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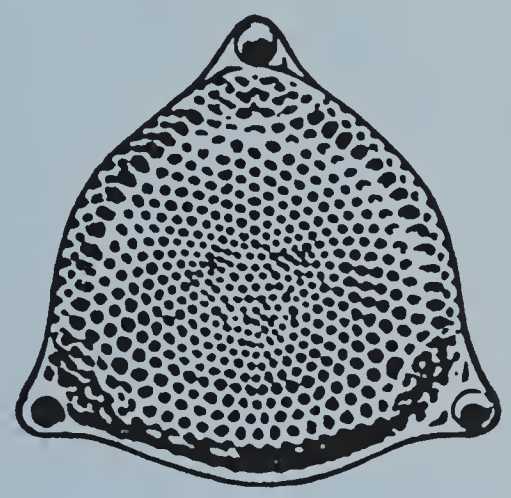

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ERRATUM

Numbers of 3 and 4 of Volume 72 mistakenly carry the date of 1980. They should instead read 1979.

NOTICE

Dr. Basil C. Hedrick has resigned as editor of the Transactions of the Illinois State Academy of Science effective with the final publication of Volume 73 (1980). Beginning with Volume 74 (1981) the editorship will be shared by Dr. Anthony Paparo and Dr. L. Richard Coulson, Southern Illinois University School of Medicine, Southern Illinois University at Carbondale, Carbondale, Illinois 62901. Please address all manuscripts and editorial correspondence to their attention.

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BERTRANDITE AT HICKS DOME, HARDIN COUNTY, ILLINOIS

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ABSTRACT

Bertrandite, a berylium silicate, has been discovered in two occurences of intrusive breccia at Hicks Dome in the northwest corner of the Illinois-Kentucky Fluorspar District. Chemical analyses showed that the relatively high amounts of Be were present in breccia cuttings from an exploration drill hole near the center of the dome. Processing of the drill cuttings by HC1 leach, particle sizing, and heavy liquid separations at various gravities produced a Be concentration in which bertrandite was tentatively identified by optical measurements in oil immersions. This determination was confirmed by x-ray diffraction analyses of optically identical crystals concentrated from a breccia outcrop on the west flank of the dome.

INTRODUCTION

Abnormal amounts of berylium were detected in cutting of breccia from the Henry Hamp, Jr., No. 1 test well (Trace, 1960) on the apex of Hicks Dome, Hardin County, Illinois (NE¼ NW¼ SE¼ Sec. 30, T. 11 S., R. 8 E.). This prompted investigations in our laboratories that led to the tentative identification of the beryllium silicate, bertrandite, in selected samples of the well cuttings. Subsequent field mapping and sampling of surface exposures of breccia at Hicks Dome revealed additional beryllium mineralization in a shale breccia dike on the west flank of the dome. Petrographic and mineralogic investigations of the shale breccia revealed discrete crystals of bertrandite. Although the detection of bertrandite by x-ray diffraction of a sample of Hicks Dome breccia has been reported previously (Anon., 1977), we deemed it worthwhile to record the manner of occurrence of the bertrandite and its mineralogic characteristics in the Hicks Dome breccias.

HICKS DOME BRECCIAS AND MINERALIZATION

Geologic Setting

Hicks Dome is an oval structural and topographic high, located in the northwestern part of the Illinois-Kentucky Fluorspar District. Its long axis trends northwest-southeast (Weller *et al.*, 1920; Weller, Grogan, and Tippie, 1952; Baxter and Desborough, 1965; Baxter, Desborough, and Shaw, 1967), and it is superimposed on a highly faulted, broad, gentle arch (Heyl *et al.*, 1965) that extends to the southeast through the fluorspar district (Fig. 1). The central high at Hicks Dome exposes limestone and chert of Devonian age and is surrounded by a low belt of the Devonian New Albany Shale Group, which is in turn encircled by a ridge of chert, siltstone, and limestone of the Fort Payne Formation (Mississippian). A complex pattern of faulting, brecciation, mineralization, and intrusion by igneous rocks suggests that the dome was formed by an explosive release of gases (Brown, Emery, and Meyer, 1954; Heyl *et al.*, 1965; Bradbury and Baxter, in preparation).

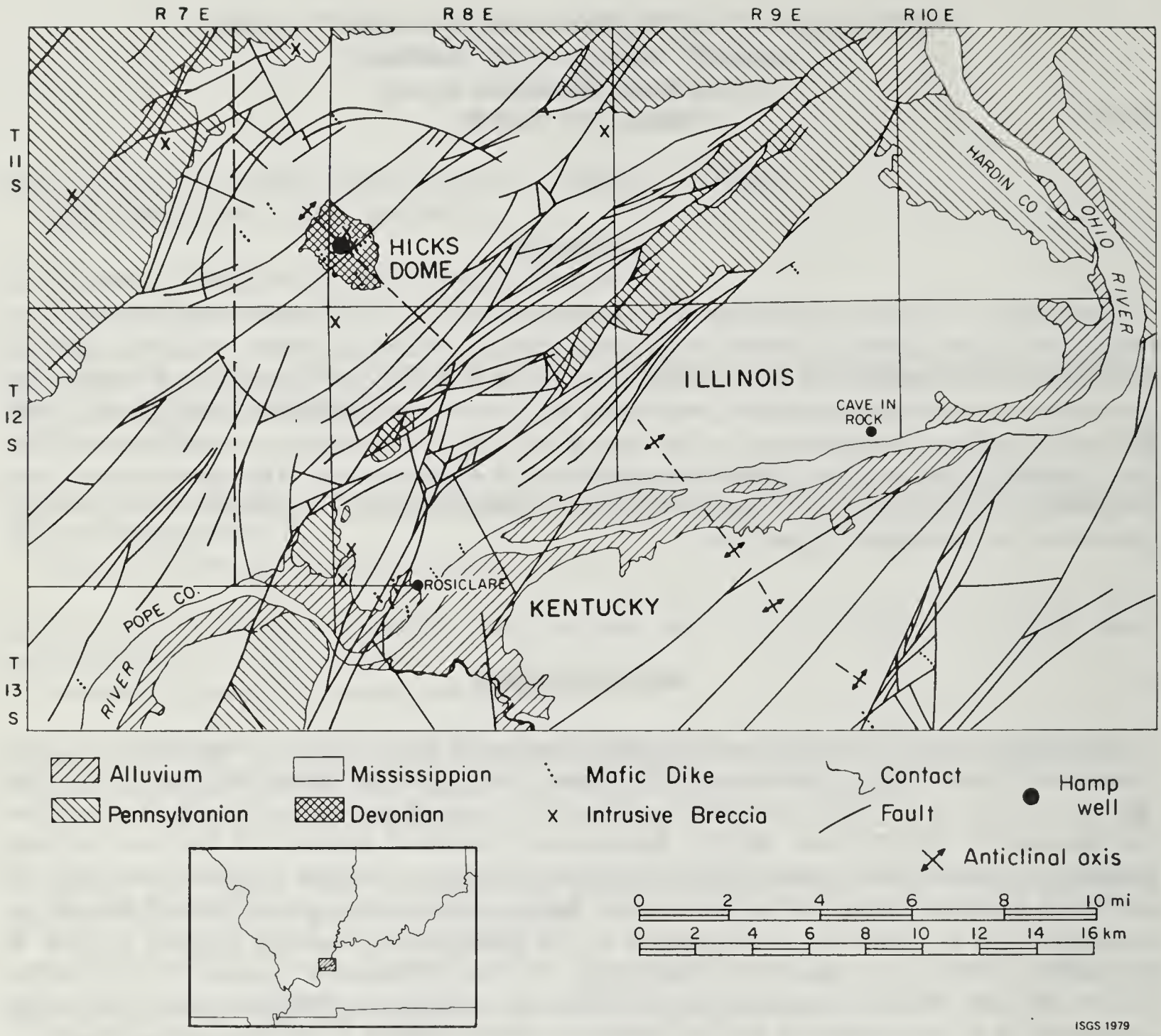


Figure 1. Geologic map of Hicks Dome and adjacent portions of the Illinois-Kentucky mining district (adapted from Grogan and Bradbury, 1968). Published with permission of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc.

Hamp Well Subsurface Breccia

The mineralized subsurface breccia encountered in the Hamp Well (Fig.2) consisted of a mixture of broken and finely comminuted sedimentary rocks. Rock particles varied widely in lithology; they also showed evidence of mixing of materials from different formations and rock systems. Some samples were an ''agglomeration of sandstones, quartzites, limestones, dolomites, and shales'' (Brown, Emery, and Meyer, 1954). Megascopic mineralization consisted of fluorite, assaying as much as 11 percent on samples from 5-foot (1.5-m) intervals, and traces of sphalerite and galena. Radiometric analyses on 25-to 30-foot (7.6- to 9.1-m) composite samples showed up to four times the normal background values. These anomalous values appeared to be caused by the presence of thorium (Brown, Emery, and Meyer, 1954).

Beryllium content

Chemical and semiquantitative analyses of those samples from representative portions of the Hamp Well that showed the greatest radioactivity was reported by Trace (1960). He demonstrated that the radioactivity was related to thorium and associated with increases in berylium, niobium, and rare earths. Three depth intervals were identified as having the greatest beryllium contents: 1725 to 1750 feet (526 to 533 m), 1785 to 1815 feet (544 to 553 m), and 2150 to 2175 feet (655 to 663 m). Samples from each interval were found to have 0.06 percent Be by semiquantitative spectrographic analysis (Trace, 1960, p. B64, table 30.2).

Surface Breccias

Most of the breccias that crop out on Hicks Dome consist of silicified fragments, essentially from the immediately enclosing rocks, in a matrix of finely comminuted rock and microcrystalline quartz. This contrasts with the lithologic admixture found at depth in the Hamp Well. The locally derived breccias include not only bodies in Devonian limestone in the central portion of the dome, but also a series of dikelike exposures showing an arrangement that is roughly radial to the center of the dome (Fig. 2). The geometry of the surface breccias and their relationship to country rock and to Hicks Dome suggest that these bodies are ''burst'' or ''shatter'' breccias formed by the rapid dilation of fractures upon the explosive release of gases (Bradbury and Baxter, in preparation).

Bradbury, Ostrom, and McVicker (1955) first described the breccia dikes as fault (?) breccias, but also suggested an alternative theory of formation involving explosive release of gases. Our subsequent field work revealed numerous additional occurrences which range from a few inches (cm) up to 10 feet (3 m) in width, are essentially vertical, and occur within the Fort Payne Formation and the New Albany Shale. Some can be seen extending 200 to 300 feet (60 to 90 m), but those enclosed by shale are poorly exposed, and known occurrences in shale are confined to creek beds. A strike diagram of 19 dikes shows clustering around two major directions of faulting in the Illinois Fluorspar District: north 50° to 60° east, and north 30° west (Fig. 2).

Known surface mineralization is mostly confined to breccias of the central area and the immediate surrounding belt of New Albany Shale. Fluorite and barite are most common, and an abandoned fluorite mine is located on the east flank of the dome at the edge of the central area. Other minerals previously recognized include minor amounts of sphalerite and galena and a single report of monazite and florencite (Trace, 1960).

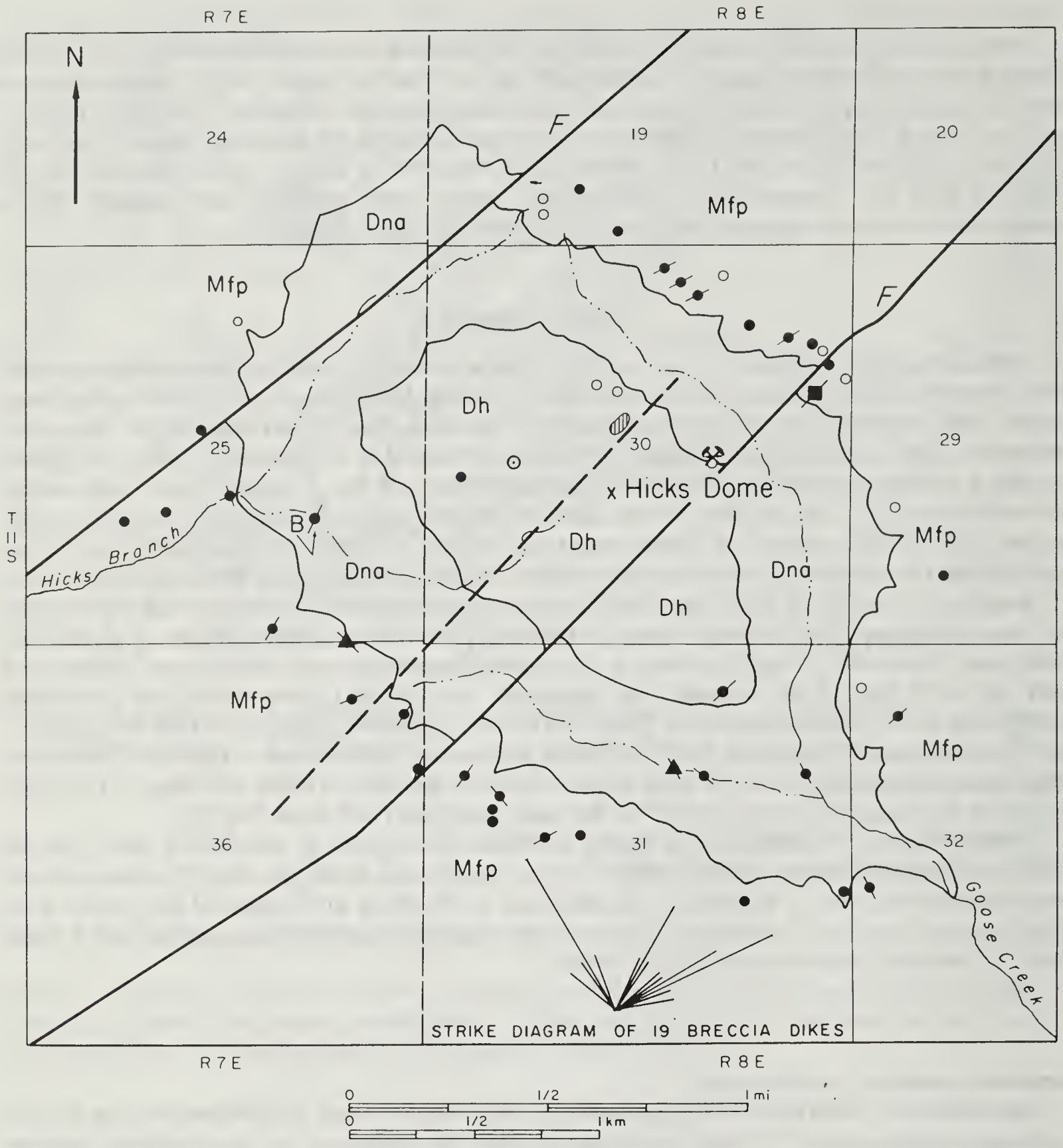
Beryllium content of a breccia dike

Spectrographic analyses showed an anomalous beryllium content (0.024 percent) for a single northeast-trending, 4-inch (10-cm) wide breccia dike that crops out on the southwest flank of Hicks Dome and is enclosed within the New Albany Shale (Bradbury and Baxter, in preparation). This breccia is composed of relatively unaltered, rotated fragments of laminated, carbonaceous, dolomitic, dark brown shale set in a cement that is mainly composed of calcite, with some dolomite, ankerite, quartz, and purple and lighter-colored fluorite (Plate 1, Fig. a).

MINERALOGIC INVESTIGATIONS

Hamp Well Breccia

Samples. A set of drilling samples, representing 5-foot sample intervals and submitted to the Illinois State Geological Survey by St. Joe Minerals Company, served as the basis of our investigations. Representative cuts of those samples that were richest in Be (Trace, 1960) were analyzed spectrographically. Samples from intervals of 1730-1735 feet, (527-529 m) and 1740-1745 feet, (530-532 m), containing 0.20 and 0.17 percent Be, respectively, were chosen for further investigation. These samples appeared to consist chiefly of broken and finely comminuted carbonate rock.



- Locally derived breccia, outcrop
- Sample, boulders
- Locally derived breccia dike, strike indicated
- Probably same, strike not determined
- Deep-seated breccia, strike indicated
- Lamprophyre, strike indicated
- Abandoned mine
- ⊙ Hamp well
- B Bertrandite occurrence
- F Fault
- Mfp Fort Payne Formation and younger
- Dna Devonian New Albany Shale
- Dh Devonian Hunton Limestone Megagroup

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Figure 2. Distribution of breccia exposures and orientation of breccia dikes.

Beryllium concentration procedures. Preliminary tests, monitored by spectrographic analysis, indicated that the beryllium minerals were insoluble in dilute HC1, were less than 270 mesh in particle size, and had a specific gravity between 2.5 and 2.6. Based on the results of these tests, we followed a concentration scheme consisting of: (1) an acid leach in 20 percent HC1; (2) grinding of the residue to pass 270 mesh; (3) separation and recovery of the $<2\mu$m fraction by settling in water and decantation; and (4) gravity separations of the $>2\mu$m fractions in bromoform-acetone mixtures. This scheme recovered a <2.62 specific gravity product that contained 1.2 percent Be, representing a sevenfold concentration of beryllium. Table 1 shows the results of analysis of the gravity fractions and the $<2\mu$m particle-size separate. The small amounts of Be in the other gravity fractions probably represent portions of the beryllium mineral not freed by the 270-mesh grind, particularly because the amount of Be decreases progressively with increasing specific gravity. The very small amount of Be in the $<2\mu$m material indicates that little Be was lost to overgrinding.

TABLE 1. Be content of various fractions from insoluble residue of sample 1740-45.

Sample no.	Mesh size	Specific gravity	Weight of Sample (g)	Be (%)
H-38	$-270 + 2\ \mu$m	<2.62	0.41	1.20
H-39	$-270 + 2\ \mu$m	2.62 – 2.81	2.74	0.29
H-40	$-270 + 2\ \mu$m	>2.81	2.26	0.18
H-41	$-2\ \mu$m			0.07

Tentative identification of beryllium mineral. X-ray diffraction of the beryllium concentrate failed to produce any peaks identifiable with a beryllium mineral, suggesting that no specific mineral was present in an amount greater than about 5 percent. Microscopic examination of the concentrate in oil immersions disclosed about 5 percent (by visual estimate) of single, platy grains, and aggregates of platy grains that appeared to have refractive indices and other optical characteristics of bertrandite. Another heavy liquid separation, performed on the concentrate at 2.57 specific gravity, produced a float crop that generated x-ray diffraction peaks of low intensity coincident with the major peaks of bertrandite. A microscopic examination of the re-concentrate revealed examples of twinned crystals (Plate 1, Figs. b and c) like those subsequently recovered from the shale breccia dike exposure and identified as bertrandite.

Because the original concentrate had been assayed to have 1.2 percent Be, which calculates to about 8 percent bertrandite, we concluded that some beryllium was present in a form other than well crystallized bertrandite. The failure of the x-ray diffractogram to indicate bertrandite in the original concentrate could have been caused by either the presence of some beryllium in a mineral species other than bertrandite or poor crystallinity of some of the bertrandite (see section, "Comparisons with Other Bertrandites").

Shale Breccia Dike

Petrographic studies. Thin sections, cut from bulk samples of the mineralized shale breccia, revealed numerous, colorless, minute crystals, most of which were about 100 μm in maximum dimension (Plate 1, Fig. d), and were intimately associated with fluorite, quartz, and sparry calcite. The crystals showed moderate relief and birefringence and were biaxial negative. Favorably oriented crystals showed a tri-sector twinning (Plate 1, Fig. e). Similar twinning, with the twinning axis parallel to the acute bisectrix, has been described for a bertrandite from Cornwall,

England (Phemister, 1940). These crystals, therefore, were tentatively identified as bertrandite and as the source of the Be values.

Recovery of bertrandite. Because calcite formed the bulk of the matrix material of the shale breccia, the other epigenetic minerals—fluorite, quartz, and bertrandite—were easily freed from hand specimens of the breccia by the simple expedient of acid digestion. No grinding of either the outcrop samples or the leach residue was done. Wet sieving of the residue through 10-, 35-, 65-, 200-, and 325-mesh screens eliminated rock fragments from the finer particle sizes.

Examination of the various-sized fractions with a binocular microscope revealed that tabular crystals of bertrandite were concentrated in the pan (minus 325-mesh) and on the 325-mesh screen (minus 200-mesh). Mineral aggregates, which were composed of the tabular crystals with fluorite or quartz, were retained on the 200-mesh screen (minus 65-mesh) and to a lesser extent on the 65-mesh screen (minus 35-mesh). The concentration achieved in the minus 325-mesh samples allowed the positive x-ray identification of bertrandite as the predominant component in a mixture of bertrandite, quartz, and fluorite. Scanning electron micrographs of a twinned crystal and an aggregate of crystals are shown on Plate 1, Figures f and g, respectively.

X-RAY IDENTITY OF TWINNED CRYSTAL

A single twinned crystal from a concentrate of the shale breccia dike was mounted in a Gandolfi powder camera for x-ray diffraction analyses. After a 3-hour run, eleven d-spacings characteristic of bertrandite were identified. The d-spacings and their corresponding degree of 2Θ and intensities are shown in Table 2. Low angle x-ray scattering obscured and probably prevented detection of the (111,021) line (d Å = 3.94, intensity = 40). X-ray diffractograms of the Hicks Dome bertrandities, however, generally show low intensities for that line, although this may be related to crystal cleavage that often results in some degree of preferred orientation, even in finely ground samples.

TABLE 2. Single crystal of Hicks Dome bertrandite—3-hour Gandolfi camera run.

2Θ	d, A	I
20.3	4.37	10
28.0	3.19	10
35.4	2.54	8
39.2	2.30	2-5
40.5	2.23	3
45.5	1.99	2
53.9	1.70	1
55.3	1.66	1
59.2	1.56	2
63.0	1.478	1
72.0	1.31	3

HICKS DOME BERTRANDITES

Bertrandite at Hicks Dome occurs predominantly as minute, tabular, euhedral to subhedral crystals (Plate 1). They are mostly about 100 μm in maximum dimension and commonly twinned. In concentrates from the Hamp Well, untwinned crystals or crystal fragments are loaded with dark inclusions, but twinned crystals from both occurrences are largely free of inclusions. The optical properties of bertrandite from both occurrences are essentially identical to those given in Larsen and Berman (1934), and the refractive indices in index oils match values they cite: $\alpha = 1.591$, $\beta = 1.605$, $\gamma = 1.614$.

Twinned crystals are usually twinned on a brachydome (031) and tend to lie on the macropinacoids in immersion oils so that each portion of the twin displays a centered or slightly off-centered acute bisectrix figure—as was also observed in favorable orientations in thin sections cut from the shale breccia dike. Untwinned crystal fragments of bertrandite concentrated from the Hamp Well breccia, in samples ground to pass the 270-mesh screen, tend to give an obtuse bisectrix figure indicative of basal 001 cleavage. This cleavage has been described by Winchell (1933, p. 410) as being the best cleavage for bertrandite, and as being normal to the obtuse bisectrix. Dana and Ford (1955) cite perfect (110) and other cleavage directions for bertrandite.

The specific gravity of Hicks Dome bertrandite has not been accurately determined, but a minus 200-plus 325 mesh fraction from the shale breccia was upgraded by specific gravity separations using bromoform = acetone mixtures and crystals of quartz and orthoclase feldspar as indicators. In this manner, concentrations of fluorite with some quartz ($>\sim$2.66 sp gr), quartz and some bertrandite ($\sim$2.57-$\sim$2.66 sp gr), and bertrandite with little quartz plus one or more unidentified minerals ($\leqq$2.57 sp gr) were obtained (Fig. 3). These separations were designed primarily to obtain concentrations of the three major mineral components, but, when considered with similar evidence from concentrations achieved with samples from the Hamp Well breccia, they suggest a specific gravity between 2.5 and 2.57 for Hicks Dome bertrandite.

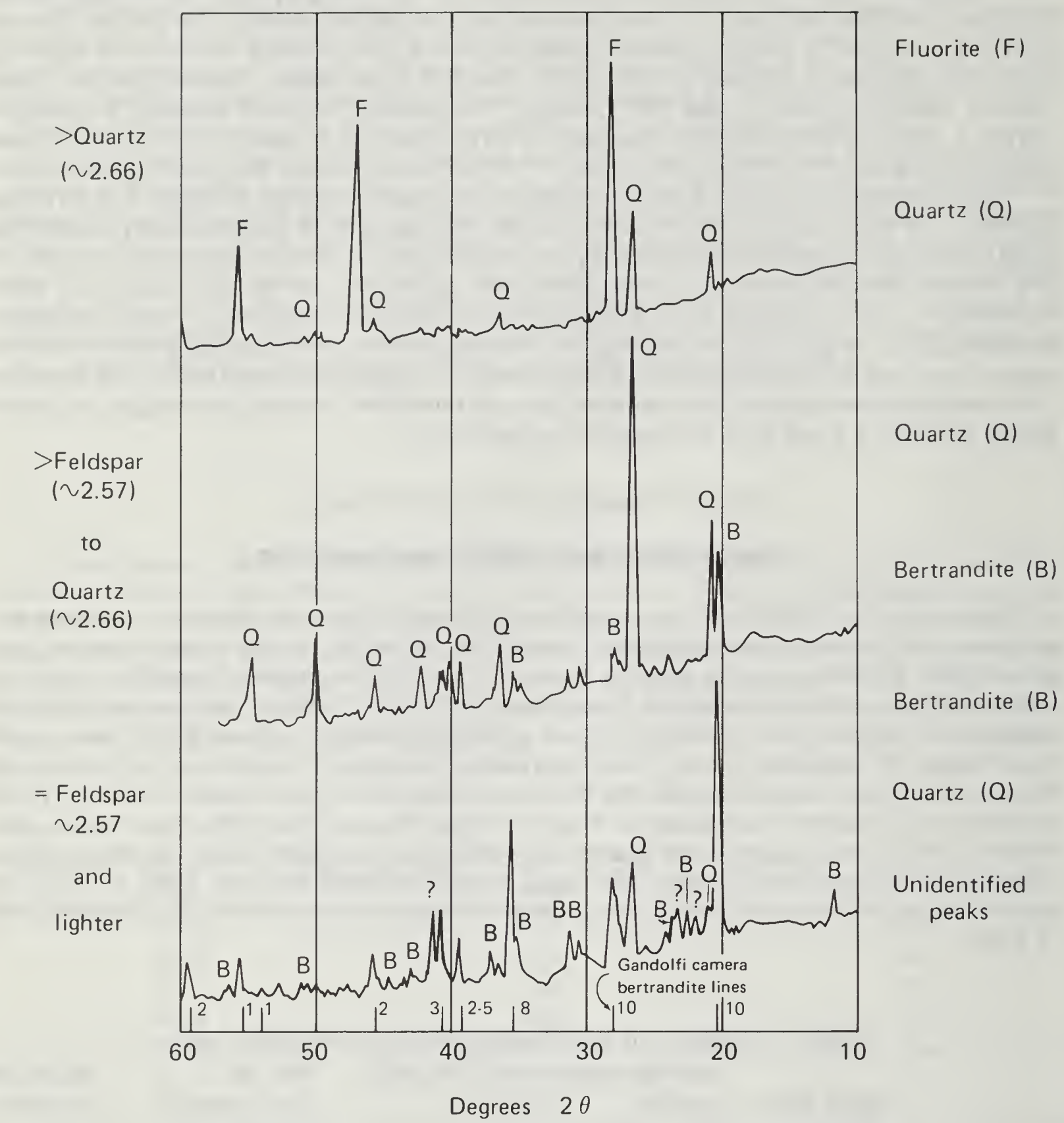
COMPARISON WITH OTHER BERTRANDITES

Bertrandite, $Be_4(OH)_2Si_2O_7$, is a beryllium dihydroxydisilicate of which both hydrated and anhydrous forms have been described. Occurrences accredited to the mineral species vary considerably in terms of water content, physical characteristics, optical properties, and x-ray diffraction data. A concentration of Hicks Dome bertrandite sufficient for accurate chemical analysis has not yet been obtained, nor has a thermogravimetric analysis (TGA) been made. Nevertheless, a comparison of the physical and optical properties of Hicks Dome bertrandite with those of other bertrandites indicates that the Illinois occurrence is more closely related to typical varieties than to hydrated forms such as those from Spor Mountain, Utah (Montoya, Havens, and Bridges, 1962) and gel bertrandite (Semenov, 1957) from the USSR (Table 3). Although the optical properties compare favorably with typical bertrandite (Dana and Ford, 1955, p. 632), our rough estimate of the specific gravity is lower than the range commonly cited for bertrandite (2.59 to 2.60).

TABLE 3. Physical and optical properties for several bertrandites

	Hicks Dome	Gerl bertrandite* (USSR)	Spor Mountain, Utah†	Mt. Isa, Queensland‡	Boomer Mine, Colorado§
Color	Colorless	Pale violet	?	Colorless	Pale pink
Crystallinity	Fine crystalline	Colloidal	Microcrystalline to cryptocrystalline	Crystalline	Crystalline
Cleavage	(001), other	—	—	(001) (010), other	?
Habit	Tabular	—	—	Tabular	?
Specific Gravity	2.50—2.57	2.176	2.3—2.4	2.60	?
Birefringence	.023	Isotropic	Weak	0.025	?
Refractive Index	$\alpha = 1.591\pm$, $\beta = 1.605\pm$, $\gamma = 1.614\pm$	1.511—1.53	1.54—1.58	$\alpha = 1.589$, $\beta = 1.603$, $\gamma = 1.613$	
Axial angle	$\sim 75°$	—	—	$\sim 80°$	?

*Source: Semenov, 1957; Montoya, Havens, and Bridges, 1962.
†Source: Montoya, Havens and Bridges, 1962.
‡Source: Vernon and Williams, 1960.
§Source: Sharp and Hawley, 1960.



Smoothed x-ray (cu Kα) diffractometer traces for gravity fractions separated from acid-insoluble portion of mineralized shale breccia.

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Figure 3. Smoothed x-ray (cu kα) diffractometer traces for gravity fractions separated from acid-insoluble portion of mineralized shale breccia (− 200 + 325 mesh).

Table 4. X-ray diffraction data for several betrandites

Hicks Dome, Illinois		Gel bertrandite (USSR) * †		Spor Mountain, Utah †		Mt. Isa, Queensland ‡		Boomer Mine, Colorado †	
d, A	I/I_o	d, A	I/I_o	d, A	I/I_o	d, A	I/I_o	d, A	I/I_o
7.56	10	-	-	7.62	7	7.56	10	7.76	6
-	-	4.81	10	-	-	-	-	-	-
4.37	100	4.31	100	4.39	100	4.38	100	4.44	100
3.93	12	-	-	3.98	43	3.94	40	3.97	31
3.80	12	-	-	3.86	23	3.80	8	3.86	31
3.20	30	3.15	100	3.21	100	3.19	90	3.21	54
3.16	35	-	-	-	-	-	-	3.06	2
2.93	13	-	-	2.95	15	1.93	10	2.95	7
2.87	16	-	-	2.89	13	2.88	10	2.90	10
2.55	17	-	-	-	-	-	-	2.57	36
2.53	60	2.53	100	2.54	65	2.54	80	2.55	40
2.43	10	-	-	2.44	10	2.42	6	2.44	7
2.29	20	2.31	80	2.30	55	2.28	60	2.30	47
2.21	30	-	-	2.23	52	2.22	60	2.24	23
-	-	2.20	80	2.19	21	2.18	2	2.19	5
2.11	6	-	-	2.12	5	2.10	4	2.12	2
2.03	5	-	-	2.03	11	2.02	6	2.04	4
1.98	15	1.998	40	1.98	25	1.983	20	1.99	12
-	-	-	-	-	-	-	-	1.97	3
-	-	-	-	1.92	5	1.923	6	1.92	5
1.78	6	-	-	1.79	5	1.787	6	1.80	3
-	-	-	-	-	-	-	-	1.77	2
1.74	4	-	-	-	-	-	-	1.74	1
1.70	6	1.714	20	1.70	14	1.698	16	1.71	13
-	-	-	-	-	-	-	-	1.67	4
1.65	12	1.651	20	1.66	11	1.650	10	1.65	9
1.63	6	-	-	1.63	5	1.628	<2	1.64	2
-	-	-	-	1.58	7	1.57	4	1.58	3
1.55	16	1.555	40	1.56	17	1.555	30	1.56	9
		-	-	-	-	-	-	1.53	1
		-	-	1.50	5	1.491	<2	1.50	2
		-	-	1.47	13	1.465	30	1.47	9
		1.454	6	-	-	-	-	1.46	3
		-	-	1.44	8	1.44	10	1.44	4
		-	-	1.42	2	-	-	1.41	1
		-	-	-	-	-	-	1.40	1
		-	-	1.38	3	-	-	1.38	1
		-	-	1.37	2	1.363	2	1.37	1
		-	-	1.35	4	1.338	4	1.34	1
		1.310	40	1.31	19	1.305	40	1.31	17

*Source: Semenov, 1957

†Source: Montoya, Havens, and Bridges, 1962.

‡Source: Vernon and Williams, 1960.

A diffraction scan through 60° 2Θ of the Hicks Dome bertrandite allowed comparison with diffraction data for other bertrandites. This comparison further confirmed our identification of bertrandite. The Hicks Dome material from the shale breccia dike has the same crystal structure as other examples (Table 4). The Hicks Dome bertrandite compares most favorably with diffraction data reported for an occurrence in the vicinity of Mica Creek near Mt. Isa, Queensland, Australia (Vernon and Williams, 1960). All major interplanar spacings for these bertrandites are recognized on diffraction scans of the Hicks Dome material. The apparent absence of some minor spacings can be explained by the incomplete nature of the mineral separations and perhaps, in part, by the degree of preferred orientation in the prepared samples.

Bertrandite is known to occur in association with both alkalic and acid igneous rocks, most commonly in pegmatitic and non-pegmatitic pneumatolytic-hydrothermal deposits (Mulligan, 1968). The geologic associations for Hicks Dome bertrandite and other occurrences, cited for comparison, are shown in Table 5. At least one lamprophyre dike and a few breccia bodies of deep-seated origin are known to occur in the immediate vicinity of Hicks Dome (Bradbury and Baxter, in preparation). The latter consist of igneous rock and mineral fragments, with varying amounts of sedimentary rock particles, in a carbonate matrix (calcite, dolomite, siderite). These are considered ''carbonatitic'' breccias formed by the upward streaming of CO_2-rich gases emanating from an alkaline magma. Other lamprophyres and similar breccias probably occur but are not exposed because they weather easily.

Table 5. Geologic associations of several bertrandites.

	Hicks Dome	Gel bertrandite USSR*	Spor Mountain, Utah†	Mt. Isa, Queensland ‡	Boomer Mine, Colorado§
Associated mineralization	Fluorite, calcite, quartz, Pb, Zn, Th, R.E.	Epidydimite beryllite	Fluorite, saponite	Beryl, mica, quartz, albite	Quartz, topaz, fluorite, beryl,
Type of deposit	Breccia dike; massive breccia	Pegmatite	Disseminated	Pegmatite	Greisen-quartz-veinlike
Wall or host rock	Shale, limestone	Nepheline syenite	Rhyolite tuff	?	Schist, granite
Igneous affinities	Alkaline	Alkaline	Acid	?	Acid

*Source: Semenov, 1957.
†Source: Vernon and Williams, 1960.
‡Source: Montoya et al., 1962.
§Source: Sharp and Hawley, 1960.

SUMMARY

The beryllium silicate, bertrandite, has been identified from a shale breccia dike that crops out on the southwest side of Hicks Dome, in Hardin County, Illinois. It compares more favorably to typical bertrandites than to hydrated forms reported from Spor Mountain, Utah. Optically similar crystals and mineral aggregates of bertrandite occur with low grade fluorspar at depth in the central portion of Hicks Dome. More detailed chemical, physical, and crystal structure investigations of these occurrences are planned.

ACKNOWLEDGMENTS

Colleagues at the Illinois State Geological Survey provided valuable assistance in various stages of our investigation of Hicks Dome bertrandite. Dr. Herbert D. Glass of the Stratigraphy and Areal

Geology Section ran some of the x-ray diffractometer analyses, advised on interpretation of diffraction patterns, and confirmed our identification of bertrandite. Ms. Suzanne J. Russell of the Coal Section provided Gandolfi camera diffraction data and scanning electron microscope views of bertrandite crystals.

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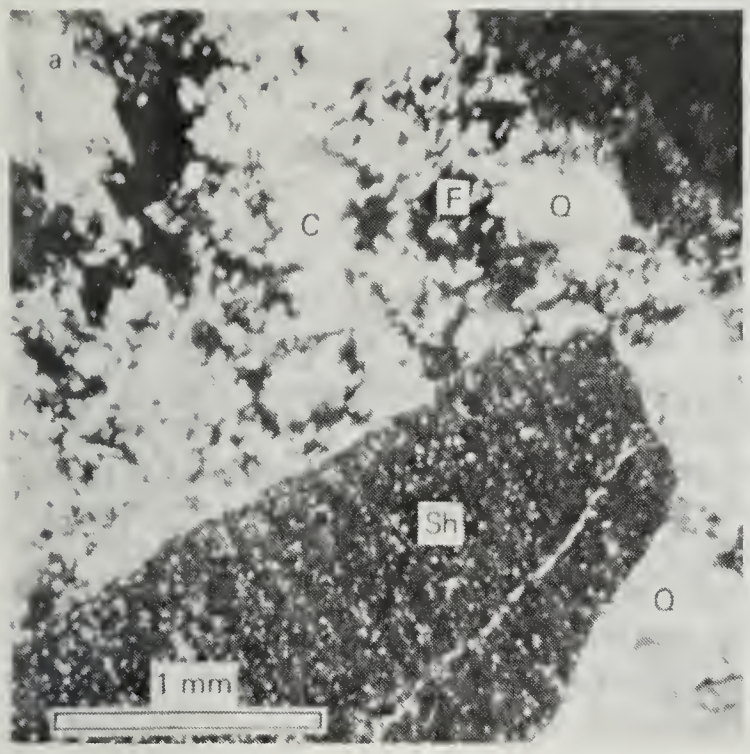
Plate 1. (Sh = shale, C = calcite, Q = quartz, f = fluorite, b = bertrandite)
Figure A. Photomicrograph of mineralized shale breccia dike showing character of brecciation.
Figure B. Photomicrograph of shale breccia dike showing relationship of bertrandite to other interstitial minerals.
Figure C. Tri-sector twinning in Hicks Dome bertrandite, crossed nichols.
Figure D. Twinned crystal of bertrandite from core breccia, 1740 to 1745 feet, (530 to 532 m); −2.57 gravity fraction, crossed nichols.
Figure E. Same as figure D, plane polarized light.
Figure F. Single twinned crystal of bertrandite, SEM view.
Figure G. Aggregate of bertrandite and fluorite, SEM view.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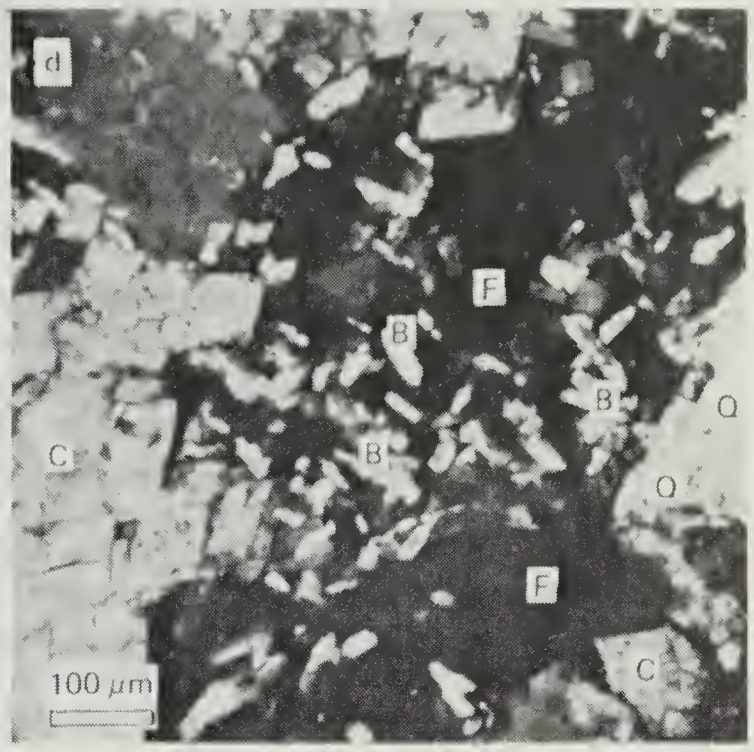
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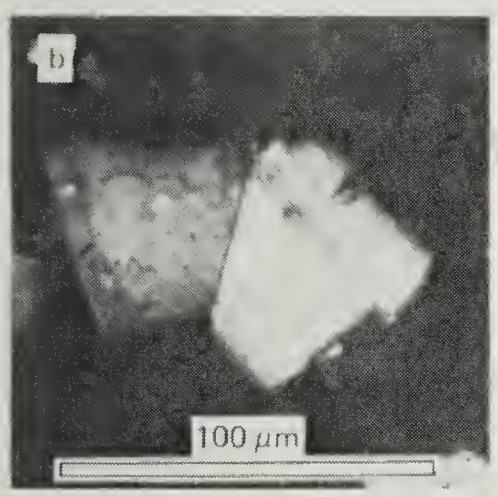
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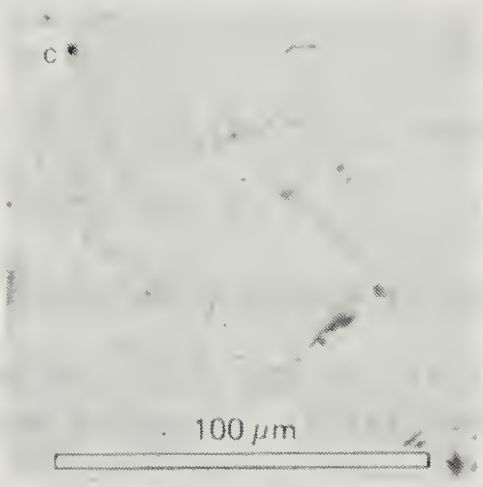
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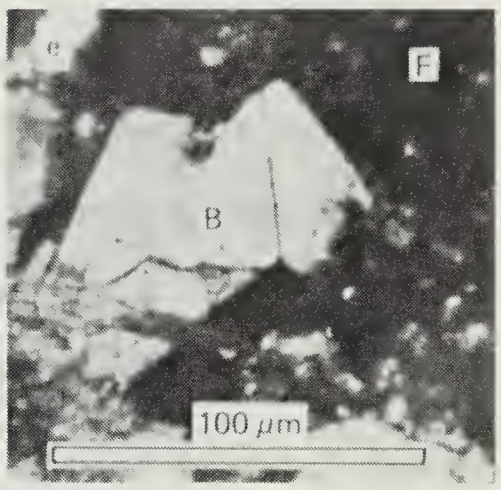
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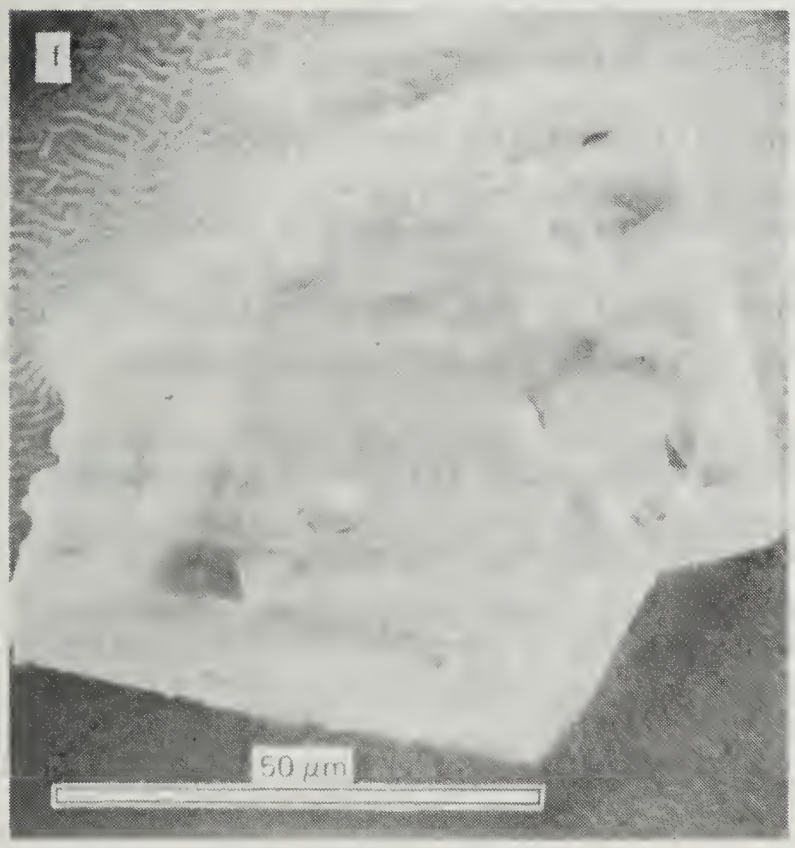
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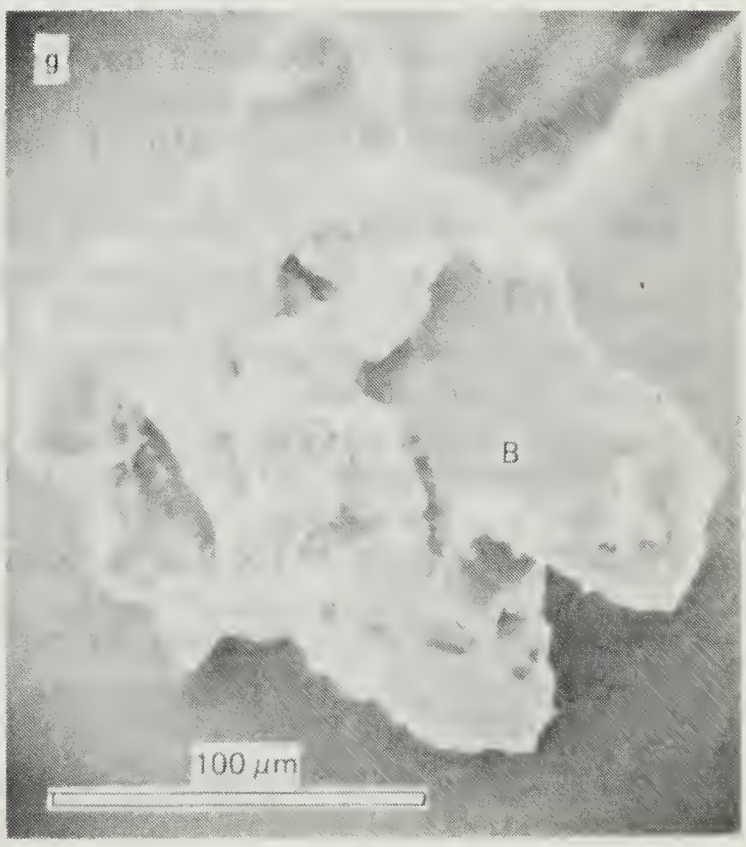
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ANALYSIS OF HIGHER ORDER MARKOV CHAINS

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A discussion of the n-dimensional matrix algebra is given. The probability distributions of second order Markov chains at various stages is discussed, and this is extended for n-order Markov chains. The steady state and the absorption characteristics of higher order Markov chains are presented in detail. Analytical methods are developed to determine the steady state probabilities and the absorption properties. The results obtained from both the analytical method and the computer are compared by the use of numerical examples. Analysis of the distribution of the process at various stages is proved to be possible as in the case of the first order Markov chains. The study of n-dimensional matrix algebra shows that $P^k = P \times P^{k-1} \neq P^{k-1} \times P$.

INTRODUCTION

The stochastic process $(X_t: \ t=0,1,2,\ldots)$ is a Markov chain if it has the following properties:

1. A finite set of possible outcomes
2. The probability of the next outcome is dependent upon its immediately preceding outcome (s) and
3. These probabilities are constant over time.

A stochastic process having the above Markov properties is said to be a first order Markov chain if the probability of the next outcome depends upon the immediately preceding outcome, a second order Markov chain if the probability of the next outcome depends upon its two immediately preceding outcomes and so on.

Higher order Markov chains are those processes for which the number of past outcomes which the process depends upon for its future states is two or more. If a process is to be analyzed by an n-order Markov chain

model, the process must have one-step probabilities. These one-step probabilities constituting the transition probability matrix characterize the process during its transition from a given condition to any other state in one step. The number of dimensions of the transition matrix depends upon the order of Markov chains. An n-order chain, for example, will have (n+1) dimensional transition matrix. For matter of simplicity, the transition matrices of second order chains are used for discussion.

Let the process $(X_t: t=0,1,2,...)$ be a second order Markov process with the state space S=(a,b). Its three dimensional transition probability matrix P in two dimensions will be as given in Fig. 1.

$$P = \begin{array}{cc} & \begin{array}{cc} t=0 & t=1 \end{array} \\ \begin{array}{c} \\ a \\ \\ b \end{array} & \begin{array}{cc} \begin{array}{c} t=2 \\ a \end{array} & \begin{array}{c} \\ b \end{array} \\ \begin{array}{cc} a & p_{aaa} \\ & b \; p_{aba} \end{array} & \begin{array}{c} p_{aab} \\ p_{abb} \end{array} \\ \begin{array}{cc} b & a \; p_{baa} \\ & b \; p_{bba} \end{array} & \begin{array}{c} p_{bab} \\ p_{bbb} \end{array} \end{array}$$

Fig. 1. Transition Matrix of a Second order Markov Process with the state space S=(a,b)

Each row in P is a probability vector describing the process exhaustively for any two past outcomes. Since each row is a probability vector, the sum of the probabilities in each row must be equal to one. The elements p_{ij}s of the matrix P are deterministic values for homogeneous processes. But they are random variables for heterogeneous processes and must be estimated as will be discussed in the later part of this paper. There are two 2-dimensional 2x2 matrices, one for every possible state at t=0. If the process does not depend upon the outcome at t=0, these two 2-dimensional 2x2 matrices reduce to a single 2-dimensional 2x2 matrix of a first order Markov chain.

The objective of this paper is to develop appropriate methods of analysis for higher order Markov chains, thus allowing them to be applied to engineering problems. The concept of n-dimensional matrix algebra is developed and this is used to analyze the distribution of the process at various stages. A reduction technique is developed for analyzing the steady state behavior of higher order homogeneous and heterogeneous Markov processes. An analytical method based upon multidimensional matrix algebra is also developed for analyzing absorption properties.

CONCEPTS OF n-DIMENSIONAL MATRIX ALGEBRA

The process of multiplication with matrices of three or more dimensions proceeds in a similar manner to the multiplication of two-dimensional matrices. An element in the product matrix is the result of the product of two uniquely defined vectors.

Even in a matrix of more than two dimensions, a vector is still identified by a fixed position in every dimension but one and it contains all elements in that dimension which are common to the fixed positions of the other dimension. For example, in a 2-dimensional matrix, a row vector is that vector in the i_1^{th} row which contains all $i_2=1,2,\ldots$ elements in the i_2^{th} row. Note that an element is uniquely defined by $i_1 i_2$ subscript.

In a three dimensional matrix, an element is uniquely identified by three subscripts, perhaps labeled $i_1 i_2 i_3$ with each letter denoting a position in that dimension. A vector may be defined by fixing two of these dimensional variables and while containing all the elements in the third dimension having the fixed subscripts in common. A vector might be labeled as $(i_1=4,\ i_2=3,\ i_3=1,2,\ldots)$ which says that it contains all the elements having $i_1=4$, $i_2=3$ in common.

To obtain an element in the product matrix, the dot product of two vectors must be obtained. For example, in a three dimensional matrix, the element (i_1=2, i_2=3, i_3=5) is the dot product of the vectors (i_1=2, i_2=3, i_3=1,2,3,...) and (i_1=3, i_2=1,2,3,..., i_3=5). In terms of notation, the product element $(2,3,5)=\sum_{k=1}^{m} (a_{23k}b_{3k5})$ for a cubic matrix of m elements on a side. In 5 dimensions, the product element $(2,3,5,4,6)=\sum_{k=1}^{m} (a_{2354k}b_{354k6})$. In the case of n-dimensional matrices of m elements on a side, the product element (1,2,4,...m-1,5) is the dot product of the row vector (i_1=1, i_2=2, i_3=4, i_{n-1}=m-1, i_n=1,2,...,m) and the column vector (i_1=2, i_2=4,...,i_{n-2}=m-1, i_{n-1}=1,2,...,m, i_n=5). It is important to observe the commutative restriction that $P^k=PxP^{k-1} \neq P^{k-1}xP$.

DETERMINATION OF THE DISTRIBUTION OF HIGHER ORDER MARKOV PROCESSES AT VARIOUS STAGES

Let the process (X_t: t=0,1,2...) be a second order Markov process with the state space S=(a,b) and the transition probability matrix P having the following numerical values:

$$P=\begin{bmatrix} p_{aaa} & p_{aab} \\ p_{aba} & p_{abb} \\ p_{baa} & p_{bab} \\ p_{bba} & p_{bbb} \end{bmatrix} = \begin{bmatrix} 0.80 & 0.20 \\ 0.60 & 0.40 \\ 0.50 & 0.50 \\ 0.30 & 0.70 \end{bmatrix}.$$

The distribution of the process at various stages 1,2,3,..., m are given by the transition probability matrices $P,P^2,P^3,...,P^m$ respectively. The elements of these transition matrices can be determined either by the exhaustive enumeration of all the possible states at various stages or by the method of matrix multiplication utilizing the concept of n-dimensional matrix algebra. In the case of exhaustive enumeration of states, the

element p^2_{aba} of P^2, for example, can be determined as follows:

Time	t=0	1	2	3
State	a	b	a or b	a

$$p^2_{aba} = p_{aba}\, p_{baa} + p_{abb}\, p_{bba} = \sum_{k=a}^{b} (p_{abk})\,(p_{bka})$$

$$= 0.6(0.5) + 0.4(0.3) = 0.42.$$

The enumeration of all the possible states for the determination of m-step probabilities will be very involved depending upon the size of the state space and the number of steps, m. In the matrix method, p^2_{aba}, for example, is the dot product of the vectors (p_{aba}, p_{abb}) and (p_{baa}, p_{bba}). In terms of notation, $p^2_{aba} = \sum_{k=a}^{b} (p_{abk})\,(p_{bka}) = 0.6(0.5) + 0.4(0.3) = 0.42$. In general, the conditional probability p^k_{aba} of P^k, is the dot product of the vectors (p_{aba}, p_{abb}) and $(p^{k-1}_{baa}, p^{k-1}_{bba})$.

In terms of notation, $p^k_{aba} = \sum_{i=a}^{b} (p_{abi})\,(p^{k-1}_{bia})$.

STEADY STATE PROPERTIES OF HIGHER ORDER HOMOGENEOUS MARKOV PROCESSES

If the system or the process being modeled as a Markov chain has certain properties, it is possible to determine the probabilities of outcomes after steady state conditions have been reached. After the process has been in operation for a long period of time, a given outcome will result x percent of time. At times, it is desirable to be able to determine these percentages. Perhaps the most detrimental assumed condition in the homogeneous processes is the requirement that the transition matrix contains probabilities which are constant over time. This requirement should always be kept in mind when this analysis is

being made to insure that the results obtained are properly interpreted.

The existance of steady state conditions in a homogeneous higher order ergodic Markov chain can be demonstrated by computing P^k for various values of k. Let the process $(X_t: t=0,1,2,...)$ be a second order Markov chain with S=(a,b) and the following transition probability matrix P:

$$P= \begin{bmatrix} p_{aaa} & p_{aab} \\ p_{aba} & p_{abb} \\ p_{baa} & p_{bab} \\ p_{bba} & p_{bbb} \end{bmatrix} = \begin{bmatrix} 0.80 & 0.20 \\ 0.60 & 0.40 \\ 0.50 & 0.50 \\ 0.30 & 0.70 \end{bmatrix}$$

The following is the computer solution of P^k for large value of K:

$$P^k= \begin{bmatrix} 0.6 & 0.4 \\ 0.6 & 0.4 \\ 0.6 & 0.4 \\ 0.6 & 0.4 \end{bmatrix}$$

As in the case of the first order Markov chains, the steady state probabilities of higher order Markov chains do not depend upon their past outcomes. Because of the complexity involved in the multiplication of higher order matrices, the analytical calculation of the steady state probabilities for higher order chains is much more difficult than in the case of first order chains. The general procedure is to reduce the probability matrix P of higher order chains to an equivalent first order matrix. The concept of reducing an n-order matrix can be demonstrated with a second order matrix. The transition matrix of the example problem given in page 4 contains two 2-dimensional 2x2 matrices, one for each state at t=0. If the process is an ergodic one, these two matrices must be the same independent of the state of the process at t=0 after a

sufficiently large number of steps K. The process at this stage is said to be in the intermediate steady state. The process has to pass through two such transitions, intermediate steady state, in order to completely eliminate the effect of the states at times t=0 and 1 upon the process for its future outcome. For the example problem, if it is assumed that the intermediate steady state is reached at the K^{th} step, then the intermediate steady state probabilities can be determined as follows:

$$p^k_{aba} = p^{k-1}_{aba}\ p_{baa} + p^{k-1}_{abb}\ p_{bba}$$
$$= p^{k-1}_{aba}\ p_{baa} + (1-p^{k-1}_{aba})\ p_{bba}$$
$$= p^{k-1}_{aba}\ (p_{baa} + p_{bbb} - 1) + (1-p_{bbb}).$$

If $X = p_{baa} + p_{bbb} - 1$ and $Y = 1-p_{bbb}$, then

$$p^k_{aba} = p^{k-1}_{aba}\ X + Y$$
$$= p_{aba}\ X^{k-1} + Y\ (1+X+\ldots X^{k-2}).$$

For large value of k,

$$p^k_{aba} = \lim_{k \to \infty} (p_{aba}\ X^{k-1} + Y(1+X+\ldots+X^{k-2}))$$
$$= Y\ (1-x)^{-1}$$
$$= \frac{1-p_{bbb}}{2-p_{baa}-p_{bbb}} = p_{ba} \qquad (1)$$

Similarly,

$$p^k_{abb} = \frac{1-p_{baa}}{2-p_{bbb}-p_{baa}} = p_{bb} \qquad (2)$$

$$p^k_{aaa} = \frac{1-p_{abb}}{2-p_{aaa}-p_{abb}} = p_{aa} \qquad (3)$$

$$p^k_{aab} = \frac{1-p_{aaa}}{2-p_{abb}-p_{aaa}} = p_{ab} \qquad (4)$$

$$p_{bba}^{k} = \frac{1-p_{bbb}}{2-p_{baa}-p_{bbb}} = p_{ba} \qquad (5)$$

$$p_{bbb}^{k} = \frac{1-p_{baa}}{2-p_{bbb}-p_{baa}} = p_{bb} \qquad (6)$$

$$p_{baa}^{k} = \frac{1-p_{abb}}{2-p_{aaa}-p_{abb}} = p_{aa} \qquad (7)$$

$$p_{bab}^{k} = \frac{1-p_{aaa}}{2-p_{abb}-p_{aaa}} = p_{ab} \qquad (8).$$

From the preceding results it is observed that at the intermediate steady state the process does not depend upon its past outcome at t=0 for its future outcome and the order of the process is reduced by one. The intermediate steady state transition matrix P_I will be as given below:

$$P_I = \begin{bmatrix} p_{aa} & p_{ab} \\ p_{ba} & p_{bb} \\ p_{aa} & p_{ab} \\ p_{ba} & p_{bb} \end{bmatrix} = \begin{bmatrix} 0.750 & 0.250 \\ 0.375 & 0.625 \\ 0.750 & 0.250 \\ 0.375 & 0.625 \end{bmatrix} .$$

It is observed that P_I consists of two identically equal 2-dimensional 2x2 matrices. The steady state probabilities for these first order matrices can be computed using the same procedure as for the determination of the intermediate steady state probabilities. The steady state probability matrix P will be as given below:

$$P_S = \begin{bmatrix} p_a & p_b \\ p_a & p_b \\ p_a & p_b \\ p_a & p_b \end{bmatrix} = \begin{bmatrix} 0.6 & 0.4 \\ 0.6 & 0.4 \\ 0.6 & 0.4 \\ 0.6 & 0.4 \end{bmatrix}$$

where $p_a = \frac{1-p_{bb}}{2-p_{aa}-p_{bb}}$ and $p_b = \frac{1-p_{aa}}{2-p_{aa}-p_{bb}}$.

The same result was obtained by the method of successive multiplication of P using the computer. From P_S it is observed that the process does not depend upon its past outcomes at t=0 and t=1 at the end of the second intermediate steady state.

The knowledge of the steady state probability distributions of second order Markov chains can be utilized for developing a generalized procedure to determine the steady state distributions of n-order Markov chains. Let the process $(X_t: t=0,1,2,...)$ be an n-order Markov chain with the state space S=(a,b) and the one-step transition matrix P. The process will have to pass through n intermediate steady states to reach the steady state. The dependency of the process upon its past outcomes will be reduced by a rate of one per intermediate steady state as the process passes through the intermediate steady states. During each reduction, the process is assumed to be a first order chain as far as the reduction is concerned and the past outcome for which the reduction is being carried out. Let π represent the ordered sequence of the outcomes of the process from t=1 to n-1. In the case of the first intermediate steady state,

$$p^k_{a\,\pi a} = p^k_{b\,\pi a} = p_{\pi a} = \frac{1-p_{bb}}{2-p_{aa}-p_{bb}}$$

The values of the other elements are determined in a similar manner. The process will need n-1 more reductions to reach the steady state. The elements of the transition matrices for these n-1 reductions can be determined in a similar manner.

ABSORPTION PROPERTIES OF HIGHER ORDER MARKOV PROCESSES

The following information may be obtained from the analysis of

higher order absorbing Markov chains.

1. The expected number of times the process is in any non-absorbing state S_j described by the series $E=I+N+N^2+N^3+\ldots$

and 2. The probability of absorption by any given absorbing state S_j given by $B=A+NA+N^2A+N^3A+\ldots$

where I, A, and N are the submatrices of the transition probability matrix P. The submatrix I is an identity matrix, the submatrix A contains the one step probabilities of going from any non-absorbing state to any other non-absorbing state, and N describes the transitions between non-absorbing states.

A numerical example is given to explain the absorption properties of higher order Markov chains. Let the process $(X_t: t=0,1,2,\ldots)$ be a second order Markov chain with the state space S=(a,b,c) and the following transition matrix P with C as the absorbing state:

$$P = \begin{bmatrix} p_{aaa} & p_{aab} & p_{aac} \\ p_{aba} & p_{abb} & p_{abc} \\ p_{aca} & p_{acb} & p_{acc} \\ p_{baa} & p_{bab} & p_{bac} \\ p_{bba} & p_{bbb} & p_{bbc} \\ p_{bca} & p_{bcb} & p_{bcc} \\ p_{caa} & p_{cab} & p_{cac} \\ p_{cba} & p_{cbb} & p_{cbc} \\ p_{cca} & p_{ccb} & p_{ccc} \end{bmatrix} = \begin{bmatrix} 0.3 & 0.3 & 0.4 \\ 0.2 & 0.2 & 0.6 \\ 0 & 0 & 1 \\ 0.5 & 0.4 & 0.1 \\ 0.4 & 0.2 & 0.4 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix}$$

The following are the submatrices A and N for the numerical example:

$$A = \begin{bmatrix} p_{aac} \\ p_{abc} \\ p_{bac} \\ p_{bbc} \end{bmatrix} = \begin{bmatrix} 0.4 \\ 0.6 \\ 0.1 \\ 0.4 \end{bmatrix} \text{ and } N = \begin{bmatrix} p_{aaa} & p_{aab} \\ p_{aba} & p_{abb} \\ p_{baa} & p_{bab} \\ p_{bba} & p_{bbb} \end{bmatrix} = \begin{bmatrix} 0.3 & 0.3 \\ 0.2 & 0.2 \\ 0.5 & 0.4 \\ 0.4 & 0.2 \end{bmatrix}$$

The solution matrix E of the series can be determined if the values of N^2, N^3,... can be found. Using the concept of n-dimensional matrix algebra, the following computer solution was obtained for the numerical example:

$$I+N+N^2+\ldots = \begin{bmatrix} 1.70 & 0.66 \\ 0.63 & 1.53 \\ 2.10 & 0.94 \\ 1.05 & 1.72 \end{bmatrix} .$$

An analytical method is developed to find the expected number of times that the process is in any non absorbing state. For the numerical example:

$$E = I+N+N^2+\ldots = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} + \begin{bmatrix} \sum_{i=1}^{M8} p^i_{aaa} & \sum_{i=1}^{M8} p^i_{aab} \\ \sum_{i=1}^{M8} p^i_{aba} & \sum_{i=1}^{M8} p^i_{abb} \\ \sum_{i=1}^{M8} p^i_{baa} & \sum_{i=1}^{M8} p^i_{bab} \\ \sum_{i=1}^{M8} p^i_{bba} & \sum_{i=1}^{M8} p^i_{bbb} \end{bmatrix} .$$

It can be shown that

$$\sum_{i=1}^{M8} p^i_{aaa} = p_{aaa}(1+\sum_{i=1}^{M8} p^i_{aaa}) + p_{aab} \sum_{i=1}^{M8} p^i_{aba}$$

$$\sum_{i=1}^{M8} p^i_{aab} = p_{aaa} \sum_{i=1}^{M8} p^i_{aab} + p_{aab} (1+\sum_{i=1}^{M8} p^i_{abb})$$

$$\sum_{i=1}^{M8} p^i_{aba} = p_{aba} (1+\sum_{i=1}^{M8} p^i_{baa}) + p_{abb} \sum_{i=1}^{M8} p^i_{bba}$$

$$\sum_{i=1}^{M8} p^i_{abb} = p_{aba} \sum_{i=1}^{M8} p^i_{bab} + p_{abb} (1+\sum_{i=1}^{M8} p^i_{bbb})$$

$$\sum_{i=1}^{M8} p^i_{baa} = p_{baa} (1+\sum_{i=1}^{M8} p^i_{aaa}) + p_{bab} \sum_{i=1}^{M8} p^i_{aba}$$

$$\sum_{i=1}^{M8} p^i_{bab} = p_{baa} \sum_{i=1}^{M8} p^i_{aab} + p_{bab} (1+\sum_{i=1}^{M8} p^i_{abb})$$

$$\sum_{i=1}^{M8} p^i_{bba} = p_{bba}\,(1+\sum_{i=1}^{M8} p^i_{baa}) + p_{bbb}\sum_{i=1}^{M8} p^i_{bba}$$

$$\sum_{i=1}^{M8} p^i_{bbb} = p_{bba}\sum_{i=1}^{M8} p^i_{bab} + p_{bbb}\,(1+\sum_{i=1}^{M8} p^i_{bbb}).$$

The following results are obtained by solving the preceding eight simultaneous equations:

$$\sum_{i=1}^{M8} p^i_{aaa} = 0.70 \qquad \sum_{i=1}^{M8} p^i_{aab} = 0.66$$

$$\sum_{i=1}^{M8} p^i_{aba} = 0.63 \qquad \sum_{i=1}^{M8} p^i_{abb} = 0.53$$

$$\sum_{i=1}^{M8} p^i_{baa} = 1.10 \qquad \sum_{i=1}^{M8} p^i_{bab} = 0.94$$

$$\sum_{i=1}^{M8} p^i_{bba} = 1.05 \qquad \sum_{i=1}^{M8} p^i_{bbb} = 0.72 \quad .$$

For these values,

$$I+N+N^2+\ldots = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} + \begin{bmatrix} 0.70 & 0.66 \\ 0.63 & 0.53 \\ 1.10 & 0.94 \\ 1.05 & 0.72 \end{bmatrix} = \begin{bmatrix} 1.70 & 0.66 \\ 0.63 & 1.53 \\ 2.10 & 0.94 \\ 1.05 & 1.72 \end{bmatrix} .$$

Negligible difference is observed if the results of the computer and the analytical solutions are compared. The preceding analytical method may be used to formulate a generalized procedure for determining the expected number of times that an n-order chain is in any non-absorbing state before absorption.

Let the process $(X_t:\ t=0,1,2\ldots)$ be an n-order Markov chain with the state space $S=(a,b,\ldots,m)$. If m is the absorbing state, then the non-absorbing submatrix N will have $(m-1)^n$ elements giving $(m-1)^n$ equations in $(m-1)^n$ unknowns, and these equations can be solved for the unknowns.

The probability of absorption by any given absorbing state described by the series $B=A+NA+N^2A+...$ can be determined if NA, N^2A,... can be found out. The values of NA, N^2A,... can be determined using the concept of n-dimensional matrix algebra. To find the value of N^2A, for example, the product NA must be determined as the first step. This product NA is then used to find the product $N(NA)$ which is equal to N^2A. The series $A+NA+N^2A+...$ can be expressed in terms of the order of multiplication of the matrices as follows:

$A+NA+N^2A+N^3A+...=A+NA+N(NA)+N(N(NA))+...$ using the preceding concept of matrix multiplication the value of the series can be determined by the use of computer.

HETEROGENEOUS HIGHER ORDER MARKOV PROCESSES

The homogeneous higher order Markov processes discussed in the previous sections are characterized by time invariant transition matrices. In many practical problems, higher order Markov processes are heterogeneous with time variant transitions. These heterogeneous processes have the same mechanism as that of the homogeneous processes except that the parameters of their transition matrices are random variables. The matrix approach proposed earlier for the homogeneous processes can also be used for the transient analysis of higher order heterogeneous processes. The steady state or long run probabilities of heterogeneous higher order Markov processes can be obtained by the following procedure:

1. Reduce the higher order heterogeneous into an equivalent first order heterogeneous model.

2. Estimate the parameters and obtain the equivalent homogeneous first order model.

To explain the preceding procedure, let the process $(X_t: \ t=0,1,2,\ldots)$ defined in the state space S=(a,b) is a second order heterogeneous Markov process. The time variant transition matrix P, of this process is the same as in Fig. 1 except that the parameters p_{ijk}s are random variables. If the reduction technique is applied once on the matrix P, the equivalent first order heterogeneous Markov chain has the following transition matrix P_I:

$$P_I = \begin{matrix} \\ a \\ b \end{matrix} \begin{matrix} \begin{matrix} a & \quad b \end{matrix} \\ \begin{bmatrix} p_{aa} & p_{ab} \\ p_{ba} & p_{bb} \end{bmatrix} \end{matrix} = \begin{matrix} \\ a \\ b \end{matrix} \begin{matrix} \begin{matrix} a & \quad b \end{matrix} \\ \begin{bmatrix} \nu+\delta & 1-\nu-\delta \\ \nu & 1-\nu \end{bmatrix} \end{matrix}$$

for $\nu \geq 0$, $\delta \geq 0$, and $\nu + \delta \leq 1$, where ν and δ are random variables having Dirichlet joint distributions.

The next step in the steady state analysis is to obtain the equivalent homogeneous first order process by estimating the parameters of the equivalent heterogeneous first order chain. The parameter estimation starts with their distribution characteristics. The random variables ν and δ are assumed to have the following Dirichlet joint distribution:

$$f(\nu,\delta) = \frac{\Gamma(c+d+e)}{\Gamma(c)\Gamma(d)\Gamma(e)} \nu^{c-1} \delta^{d-1} (1-\nu-\delta)^{e-1}$$

for $\nu \geq 0$, $\delta \geq 0$, and $\nu + \delta \leq 1$. $= 0$ otherwise.

The validity about the assumption for the joint distribution of ν and δ can be checked using Morrison's [9] method χ^2 test. For the preceding joint distribution, ν and δ will have the following Beta distributions:

$$g_1(\nu) = \frac{\Gamma(c+d+e)}{\Gamma(c)\ \Gamma(d+e)} \nu^{c-1} (1-\nu)^{d+e-1} \text{ for } 0 \leq \nu \leq 1,$$

$$g_2(\delta) = \frac{\Gamma(c+d+e)}{\Gamma(d)\ \Gamma(c+e)} \delta^{d-1} (1-\delta)^{c+e-1} \text{ for } 0 \leq \delta \leq 1.$$

The format of the equivalent homogeneous first order chain is given below:

$$P_E = \begin{array}{c} \\ a \\ b \end{array} \begin{array}{c} \begin{array}{cc} a & b \end{array} \\ \begin{bmatrix} E(\nu+\delta) & 1-E(\nu+\delta) \\ E(\nu) & 1-E(\nu) \end{bmatrix} \end{array}$$

The expected values $E(\nu+\delta)$, $1-E(\nu+\delta)$, $E(\nu)$, and $1-E(\nu)$ are determined from the marginal distributions of ν and δ. If the parameters are evaluated and substituted, the matrix P_E will be as given:

$$P_E = \begin{array}{c} \\ a \\ b \end{array} \begin{array}{c} \begin{array}{cc} a & b \end{array} \\ \begin{bmatrix} \frac{c+d}{c+d+e} & \frac{e}{c+d+e} \\ \frac{c}{c+d+e} & \frac{d+e}{c+d+e} \end{bmatrix} \end{array} .$$

The last step in the steady state analysis is to obtain the steady state or the long run probabilities from the matrix P_E. The steady state matrix is independent of the past outcomes of the process and it can be shown to be as given below:

$$P_S = \begin{array}{c} \\ a \\ b \end{array} \begin{array}{c} \begin{array}{cc} a & b \end{array} \\ \begin{bmatrix} \frac{c}{c+e} & \frac{e}{c+e} \\ \frac{c}{c+e} & \frac{e}{c+e} \end{bmatrix} \end{array} .$$

CONCLUSION

The transient and absorption properties of Markov processes are analyzed by the use of matrix algebra. The transition matrices of first order Markov chains are two dimensional resulting in the commutative matrix manipulations. Higher order Markov processes are

characterized by transition matrices with 3 or more dimensions. Because of the non-commutative properties, algebraic manipulations with higher dimensional matrices are not standardized and the n-dimensional matrix algebra developed in this paper is used only for analysis of Markov processes.

The steady state properties of higher order homogeneous Markov processes can be analyzed using computers by the use of the proposed n-dimensional matrix algebra. The proposed reduction technique in this paper can also be used if a quick manual solution for long run probabilities is desired. The steady state behavior of heterogeneous Markov processes makes a basic assumption that the one step probabilities are random variables according to the Dirichlet distribution. The validity of this assumption can be greatly improved by the proper selection of the parameters of the distribution.

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MILLIMETER WAVE AMPLIFICATION BY THE INTERACTION BETWEEN THE CYCLOTRON WAVE AND ELECTRON BEAM

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ABSTRACT

The wave interaction and performance characteristics of a new mode of microwave amplifier device are investigated. The new mode of operation involves active coupling between a fast cycletron wave and a positive kinetic power synchronous wave on an electron beam. The condition for the existence of the wave interaction and the gain expression are derived. The result shows that the effect of space charge enhances the interaction which induces high power operation. Wide band characteristics are also obtained independent of signal frequency and extremely low noise is anticipated for frequencies well into millimeter wave region. Electronic gain of 10 db has been recorded by the experimental tubes.

INTRODUCTION

Most microwave beam devices are almost exclusively designed on the principle of longitudinal interaction between space-charge waves on the electron beam and a propagating electromagnetic wave on a slow-wave circuit (Curnow, 1961; Kang et al, 1978). Traveling-wave amplifiers and backward-wave oscillators are typical examples of this kind of interaction. The noise figure of longitudinal beam tubes cannot be reduced below a certain value, which is governed by the correlation between the random current and velocity of the beam. The minimum noise figure can be reduced to approximately 3 db by the Curi's low-noise gun (Curnow, 1961). However, such a sophisticated low-noise gun technique limits the operating power-level to a very low level, and the frequency bandwidth. Gordon suggested the dc pumped quadruple amplifier to eliminate some drawback (MaO, 1962), however, it does not give a low-noise characteristic.

The microwave amplifier presented here proposes a low-noise characteristic arising from the fact that the electron beam is carrying a positive kinetic power, so that the beam noise can be stripped to an external matched load before it enters the amplifying section. Theoretically the pump section has an infinite bandwidth, since its

performance is independent of signal frequency. However, the bandwidth of the amplifier is limited by the structure of the input and output couplers.

A new mode of transverse-wave interaction which combines the desirable features of both the rf and dc pumped quadrupole amplifiers is investigated to improve the characteristics of the conventional devices. A coupled-mode analysis is applied to the amplifier device by using the general expression and then gain equation is subsequently derived. To cover large-signal operation, the analysis is extended to the electronic ballistic approach by large-signal analysis.

Based on the small-signal and large-signal analysis, experimental devices have been designed, constructed and tested. Finally, the experimental result is presented, and a comparison is also given.

SMALL SIGNAL ANALYSIS

The coupled-mode theory is used to describe the operation of microwave tubes in terms of coupling of circuit and electron beam. For large signal, the coupled-mode theory does not give an accurate description of the device operation but its simple mathematical form enables us to visualize the physical insight, in particular, the wave interaction mechanicsm and the coupling characteristics.

An electron beam is considered to vary spatially by $e^{j\omega t}$, and all variables are to be contained by dc and ac components in the form:

$$\vec{A} = \vec{A}_o + \vec{A}_1 \qquad (1)$$

and assume that $A_1 << A_o$ in the small signal analysis where subscripts o and 1 represent dc and ac components of the variable respectively. To describe electron motion, Lorentz's force equation is used as:

$$\frac{d\vec{u}}{dt} = -\eta(\vec{E} + \vec{u} \times \vec{B}) \qquad (2)$$

where u, η, E, and B are the velocity of electron beam, the charge to mass ratio of electron, electric field, and magnetic field respectively.

It is now convenient to define:

$$\frac{dx}{dt} = u_x \qquad (3)$$

$$\frac{dy}{dt} = u_y \qquad (4)$$

$$u_{\pm} = u_{1x} \pm j u_{1y} \qquad (5)$$

$$E_{\pm} = E_x \pm j E_y \qquad (6)$$

$$B_{\pm} = B_x \pm jB_y \tag{7}$$

$$F_{\pm} = E_{\pm} \pm ju_o B_{\pm} \tag{8}$$

Where u_x and u_y are the transverse beam velocities while u_o and u_1 represent the dc and ac beam velocities.

From the physical structure of the amplifier device, it is assumed that $u_o = \vec{u}_o \hat{z}$ and $\vec{B}_o = B_o \hat{z}$. Eqs (2), (3), and (4) can be put into a set of coupled-mode equations in terms of coupled-mode amplitudes as follows:

$$(\frac{d}{dt} - j\omega - \frac{1}{k}\frac{dk}{dt})\, a_1 = -\eta k F_+ \tag{9}$$

$$(\frac{d}{dt} + j\omega - \frac{1}{k}\frac{dk}{dt})\, a_2 = -\eta k F_- \tag{10}$$

$$(\frac{d}{dt} - \frac{1}{\omega_c}\frac{d\omega_c}{dt} - \frac{1}{k}\frac{dk}{dt})\, a_3 = -\eta k F_+ - \frac{1}{\omega_c}\frac{d\omega_c}{dt}\, a_1 \tag{11}$$

$$(\frac{d}{dt} - \frac{1}{\omega_c}\frac{d\omega_c}{dt} - \frac{1}{k}\frac{dk}{dt})\, a_4 = -\eta k F_- - \frac{1}{\omega_c}\frac{d\omega_c}{dt}\, a_2 \tag{12}$$

where $a_{1,2}$ = fast and slow cyclotron modes = $A_{1,2} e^{-j(\beta e \mp \beta c)z}$

$a_{3,4}$ = negative and positial synchronous modes = $A_{3,4} e^{-j\beta_c z}$

k = beam impedance $= 1/4 \sqrt{\frac{I_o \omega}{\eta \omega}}$

ω_c = cyclotron frequency $= \eta B_o$, $\beta_c = \frac{\omega_c}{u_o}$, $\beta_e = \frac{\omega}{u_o}$.

A_i = amplitude of the wave, i = 1, 2, 3, 4.

The transverse displacements and velociites can also be expressed in terms of coupled-mode amplitudes by using Eqa (9) through (12)

$$x = \frac{a_4 - a_2 - a_3 + a_1}{j2k\omega_c} \tag{13}$$

$$y = \frac{a_4 - a_2 + a_3 - a_1}{2k\omega_c} \tag{14}$$

$$u_x = \frac{a_1 + a_2}{2k} \tag{15}$$

$$u_y = \frac{a_1 - a_2}{j2k} \tag{16}$$

To simplify the analysis, assume that the ac magnetic fields in the transverse direction are negligible, $B_z = 0$ that ω_c is a constant and that $dk/dt = 0$. Since u_o is constant, $d/dt = (d/dz)\cdot(dz/dt) = u_o (d/dz)$. Differentiating Eqs (9) and (11) with respect to z, subtracting and then adding Eq (11) which is multiplied by $j\beta_c$ yields the following coupled-mode equation:

$$e^{j\beta_c z}\left(\frac{d^2A_1}{dz^2} + j\beta_c\frac{dA_1}{dz}\right) - \frac{d^2A_3}{dz^2} + j\beta_c\frac{dA_3}{dz} = -j\beta_c\frac{\eta k}{u_o}E_+ \qquad (17)$$

Similarly, from Eqs (10) and (12), the following equation is obtained:

$$e^{-j\beta_c z}\left(\frac{d^2A_2}{dz^2} - j\beta_c\frac{dA_2}{dz}\right) - \frac{d^2A_4}{dz^2} - j\beta_c\frac{dA_4}{dz} = j\beta_c\frac{\eta k}{u_o}E_- \qquad (18)$$

Equations (17) and (18) are the general expressions with the inclusion of space charge field, which can be used to analyze all types of pumped quadrupole amplifiers, as long as the pump field $E_{\pm}$ can be determined.

GAIN EXPRESSION

With a quadrifilar helix pump field, the polarized fields $E_{\pm}$ in terms of the coupled-mode amplitudes (Kang et al, 1978) are:

$$E_+ = -\frac{2V_p}{k\omega_c a^2}(A_4 - A_2 e^{-j\beta_c z})e^{j2\beta_q z} \qquad (19)$$

and

$$E_- = -\frac{2V_p}{k\omega_c a^2}(A_3 - A_1 e^{j\beta_c z})e^{-j2\beta_q z} \qquad (20)$$

where $\beta_q = \frac{2\pi}{p}$ is the phase constant of the pump field, p is the pitch of the helix, a is the radius of quadrifilar helix structure and V_p is the pump voltage.

When Eq S. (19) and (20) are substituted into EqS.(17) and (18), the coupled equations become

$$\left(\frac{d^2A_1}{dz^2} + j\beta_c \frac{dA_1}{dz}\right) e^{j\beta_c z} - \frac{d^2A_3}{dz^2} + j\beta_c \frac{dA_3}{dz} = \frac{\omega_p^2}{4\eta V_o} e^{j\beta_c z} A_1$$

$$-j \frac{V_p}{V_o a^2} e^{j(2\beta_q - \beta_c)z} A_2 - \frac{\omega_p^2}{4\eta V_o} A_3 + j \frac{V_p}{V_o a^2} e^{j2\beta_q z} A_4 \qquad (21)$$

and

$$\left(\frac{d^2A_2}{dz^2} - j\beta_c \frac{dA_2}{dz}\right) e^{-j\beta_c z} - \frac{d^2A_4}{dz^2} - j\beta_c \frac{dA_4}{dz} = j \frac{V_p}{V_o a^2} e^{j(\beta_c - 2\beta_q)z} A_1$$

$$+ \frac{\omega_p^2}{4\eta V_o} e^{-j\beta_c z} A_2 - j \frac{V_p}{V_o a^2} e^{-j2\beta_q z} A_3 - \frac{\omega_p^2}{4\eta V_o} A_4 \qquad (22)$$

Where ω_p is the plasma frequency and V_o is the dc beam voltage. Since the wave interaction occurs with $\beta_q = 1/2\beta_c$, the coupling equations between the fast cyclotron mode and positive synchronous can be found by separating Eqa. (21) and (22). These equations are

$$\frac{d^2A_1}{dz^2} + j\beta_c \frac{dA_1}{dz} - \frac{\omega_p^2}{4\eta V_o} A_1 = j \frac{V_p}{V_o a^2} A_4 \qquad (23)$$

$$\frac{d^2A_2}{dz^2} - j\beta_c \frac{dA_2}{dz} - \frac{\omega_p^2}{4\eta V_o} A_2 = -j \frac{V_p}{V_o a^2} A_3 \qquad (24)$$

$$\frac{d^2A_3}{dz^2} - j\beta_c \frac{dA_3}{dz} - \frac{\omega_p^2}{4\eta V_o} A_3 = j \frac{V_p}{V_o a^2} A_2 \tag{25}$$

and

$$\frac{d^2A_4}{dz^2} + j\beta_c \frac{dA_4}{dz} - \frac{\omega_p^2}{4\eta V_o} A_4 = -j \frac{V_p}{V_o a^2} A_1 \tag{26}$$

Assuming the $e^{\gamma z}$ variation for the couple modes, the propatation constants are found to be, from the above four equations,

$$\gamma_1 = -j\frac{\beta_c}{2} + \sqrt{M+N-\beta_c{}^2/4}$$

$$\gamma_2 = -j\frac{\beta_c}{2} - \sqrt{M+N-\beta_c{}^2/4}$$

$$\gamma_3 = -j\frac{\beta_c}{2} + j\sqrt{M-N+\beta_c{}^2/4}$$

and

$$\gamma_4 = -j\frac{\beta_c}{2} - j\sqrt{M-N+\beta_c{}^2/4}$$

where $N = \omega_p^2/4\eta V_o$ and $M = V_p/V_o a^2$.

Here γ_1 represents a growing wave of $M+N > \beta_c^2/4$. It can be noted that the critical pump condition is modified by the inclusion of space-charge effects, N. The critical pump voltage can be obtained from the information of propagation constants as

$$V_p \geq \frac{\omega_{ca}^2 a^2}{8\eta} - \frac{\omega_{pa}^2 a^2}{4\eta} \tag{27}$$

Since γ_3 and γ_4 are pure imaginary, they can be neglected in calculating the gain expression. The coupled-mode amplitudes for the fast cyclotron wave and the positive synchronous wave can be evaluated as:

$$A_1(z) = c_1 e^{\gamma z} + c_2 e^{-\gamma z} \tag{28}$$

and

$$A_4(z) = C_3 e^{\gamma z} + C_4 e^{-\gamma z} \tag{29}$$

where C_1, C_2, C_3, and C_4 are unknown constants to be determined by using boundary conditions. Substituting A_1 and A_4 into Eq. (23) yields

$$\gamma^2(C_1 e^{\gamma z} + C_2 e^{-\gamma z}) + j\beta_c\gamma(C_1 e^{\gamma z} - C_2 e^{-\gamma z}) - N(C_1 e^{\gamma z} + C_2 e^{-\gamma z})$$

$$= jM(C_3 e^{\gamma z} + C_4 e^{-\gamma z})$$

When terms with the same exponential factor are equated,

$$C_3 = \frac{1}{jM}(\gamma^2 + j\beta_c\gamma - N)\, C_1$$

and

$$C_4 = \frac{1}{jM}(\gamma^2 - j\beta_c\gamma - N)\, C_2$$

By applying an initial condition at $z = 0$,

$$A_1(0) = C_1 + C_2$$

$$A_4(0) = C_3 + C_4$$

$$= \frac{1}{jM}(\gamma^2 + j\beta_c\gamma - N)C_1 + (\gamma^2 - j\beta_c\gamma - N)\, C_2$$

Now, C_1 and C_2 can be written in terms of $A_1(0)$ and $A_4(0)$,

$$C_1 = \frac{1}{2\beta_c\gamma}\left[\{\beta_c\gamma + j(\gamma^2 - N)\; A_1(0) + MA_4(0)\}\right]$$

and

$$C_2 = \frac{1}{2\beta_c\gamma}\left[\{\beta_c\gamma - j(\gamma^2 - N)\; A_1(0) - MA_4(0)\}\right]$$

The coupled-mode amplitude of the fast cyclotron wave is then

$$A_1(z) = C_1 e^{\gamma z} + C_2 e^{-\gamma z}$$

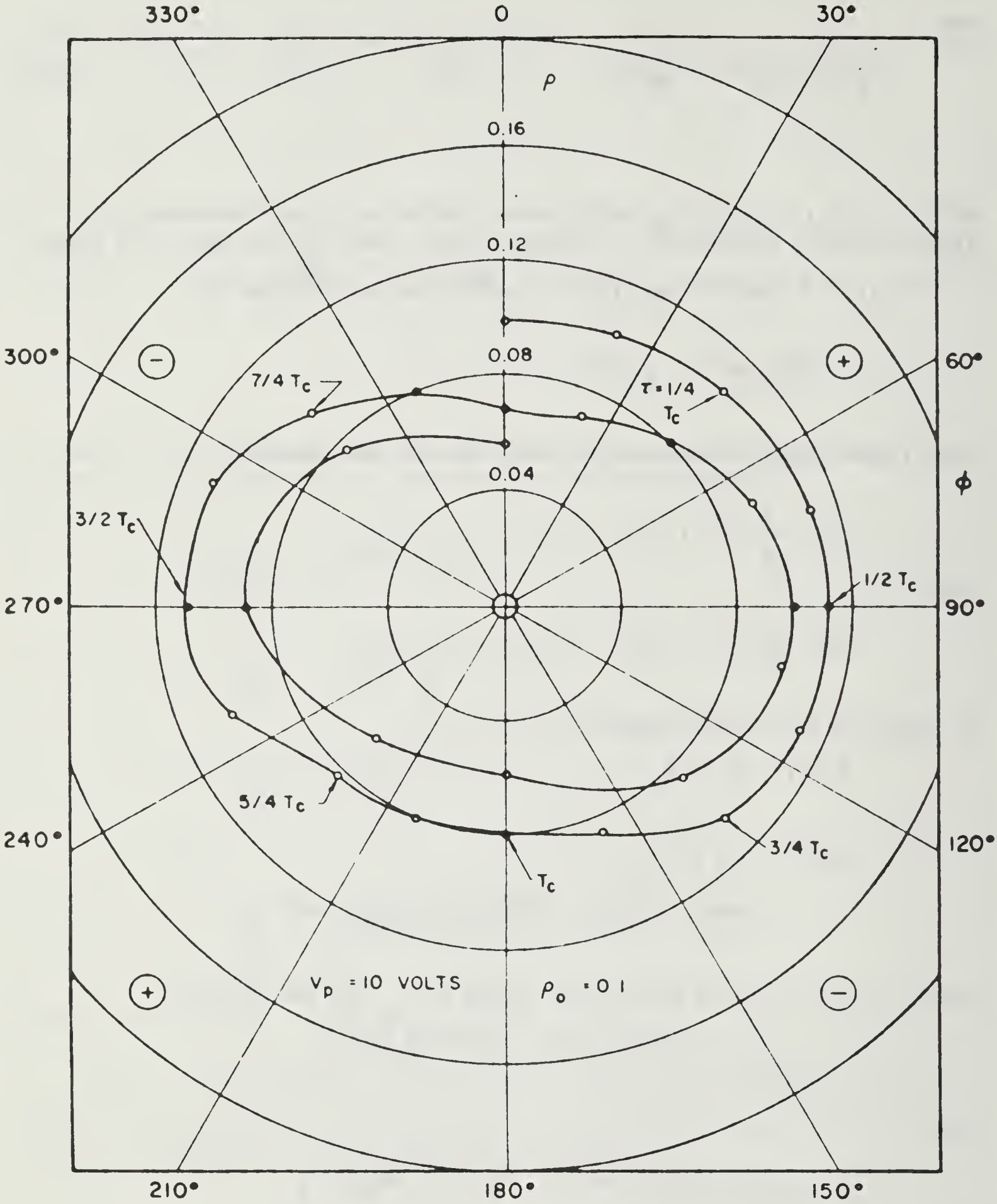

Fig. 1. CYCLOTRON-SYNCHRONOUS WAVE INTERACTION WITH A VERY LOW PUMP FIELD. (V_p = 10 volts)

$$= \left[1/2\ A_1(0) + \frac{M}{2\beta_c\gamma} A_4(0)\right] e^{\gamma z} + j\frac{(\gamma^2-N)}{2\beta_c\gamma} A_1(0) e^{\gamma z}$$

$$+ \left[1/2\ A_1(0) - \frac{M}{2\beta_c\gamma} A_4(0)\right] e^{-\gamma z} - j\frac{(\gamma^2-N)}{2\beta_c\gamma} A_1(0) e^{-\gamma z}$$

and the gain for the fast cyclotron wave is

$$\text{Gain} = \frac{\text{Re } A_1(z)}{A_1(0)}$$

$$= \cosh \gamma z + \frac{MA_4(0)}{\beta_c A_1(0)} \sinh \gamma z \qquad (30)$$

The gain expression is written in decibels by taking logarithm in both sides of Eq. (30) as

$$G = 10 \log \left[\cosh \gamma z + \frac{MA_4(0)}{\beta_c A_1(0)} \sinh \gamma z\right] \text{ db} \qquad (31)$$

ELECTRON BALLISTIC ANALYSIS

In order to understand a physical picutre of space-charge effects in the amplifier device, a particle dynamic analysis of the beam electrons is required. The euqations of electron motion for the cyclotron-synchronous wave interaction with space charge effects included can be expressed as

$$\frac{\partial^2 r}{\partial t^2} - r\left(\frac{\partial \theta}{\partial t}\right)^2 = -\eta\left(E_{sc}^r - \frac{\partial v}{\partial r} + \beta_z r \frac{\partial \theta}{\partial t} - \beta_\theta \frac{\partial z}{\partial t}\right) \qquad (32)$$

$$r\frac{\partial^2 \theta}{\partial \tau^2} + 2\frac{\partial r}{\partial t}\frac{\partial \theta}{\partial t} = -\eta\left(E_{sc}^\theta - \frac{1}{r}\frac{\partial v}{\partial \theta} - \beta_z \frac{\partial r}{\partial t} + \beta_r \frac{\partial z}{\partial t}\right) \qquad (33)$$

and

$$\frac{\partial^2 z}{\partial t^2} = -\eta\left(E_{sc}^z - \frac{\partial V_p}{\partial z} + \beta_\theta \frac{\partial r}{\partial \tau} - \beta_r r \frac{\partial \theta}{\partial t}\right) \qquad (34)$$

where E_{sc}^r, E_{sc}^θ and E_{sc}^z are the components of the space charge electric field, while B_r, B_o and B_z are the components of the magnetic field.

The computer simulation of Eqs. (32) through (34) is presented in the form of plots of electron frajectory in Fig. 1 and Fig. 2. In the figures, τ is $\omega_c t$ and T_c is the period of cyclotron frequency. The computations are based upon a fixed numerical value such as helix pitch of 8.4mm, helix radius of 1mm, magnetic field intensity of 430

gauss, beam voltage of 300 volts and beam current of 300 μa. Fig. 1 shows the trajactory for a low pump field. The radius of rotation is shown to be decreased as the beam moves along, and thus no gain can be obtained. As the pump field increases, the effect of the pump field becomes noticeable in Fig. 2.

When the pump voltage is more raised, the pump field gains control over the motion of the beam. After entering into the pump field structure, the electron beam is retarded in phase and locks into step with the pump field. The radius of rotation increases as the electrons gain energy from the pump field. Gain is therefore obtained as shown in Fig. 3. Equipotential lines of the pump field structure are also drawn in the figure to indicate how the electron gains energy during its travel.

EXPERIMENTAL RESULTS AND DISCUSSIONS

The experimental setup for the dc beam tests is shown in Fig. 4. It was required to determine the beam transmission under magnetic field conditions which yield a cyclotron frequency equal to the rf operating frequency. The experimental arrangement for rf test is shown in Fig. 5. After alignment of the amplifier in the electromagnet and application of the appropriate voltages the rf signal is applied and the magentic field is readjusted to optimize the rf output. Then the pump voltage is varied from zero up to values high enough so that beam interception occurs. The drift voltage for maximum gain is approximately 122 volts.

Fig. 6 shows the gain characteristics of cyclotron. Synchronous wave interaction at two different beam currents, 40μa and 73 μa. The interactions have no gain below a certain pump field strength and the gain increases rather rapidly at high pump fields. A maximum gain of 10.7 db is achieved at a pump voltage of 35 volts. It is noticed that the gain curve shifts to the left when a higher beam current is applied. This is due to the fact that higher beam currents result in higher beam space-charge effects which help the gain mechanism of the interaction (Vural, 1967). Another point is also observed that the device is independent of signal frequency and it shows very low noise figure for millimeter wave frequencies.

Experimental tubes were built and tested to verify the theory. The experimental result of maximum gain of 10.7 db is rather encouraging. Even though there are many factors yet to be improved to raise the output power these experiments have demonstrated the principle of operation. This amplifier has potential possibilities in high frequency, high power, broad band and low-noise operations. The principal contribution of this investigation is the discovery of a new mode of interaction in transverse beam amplifiers.

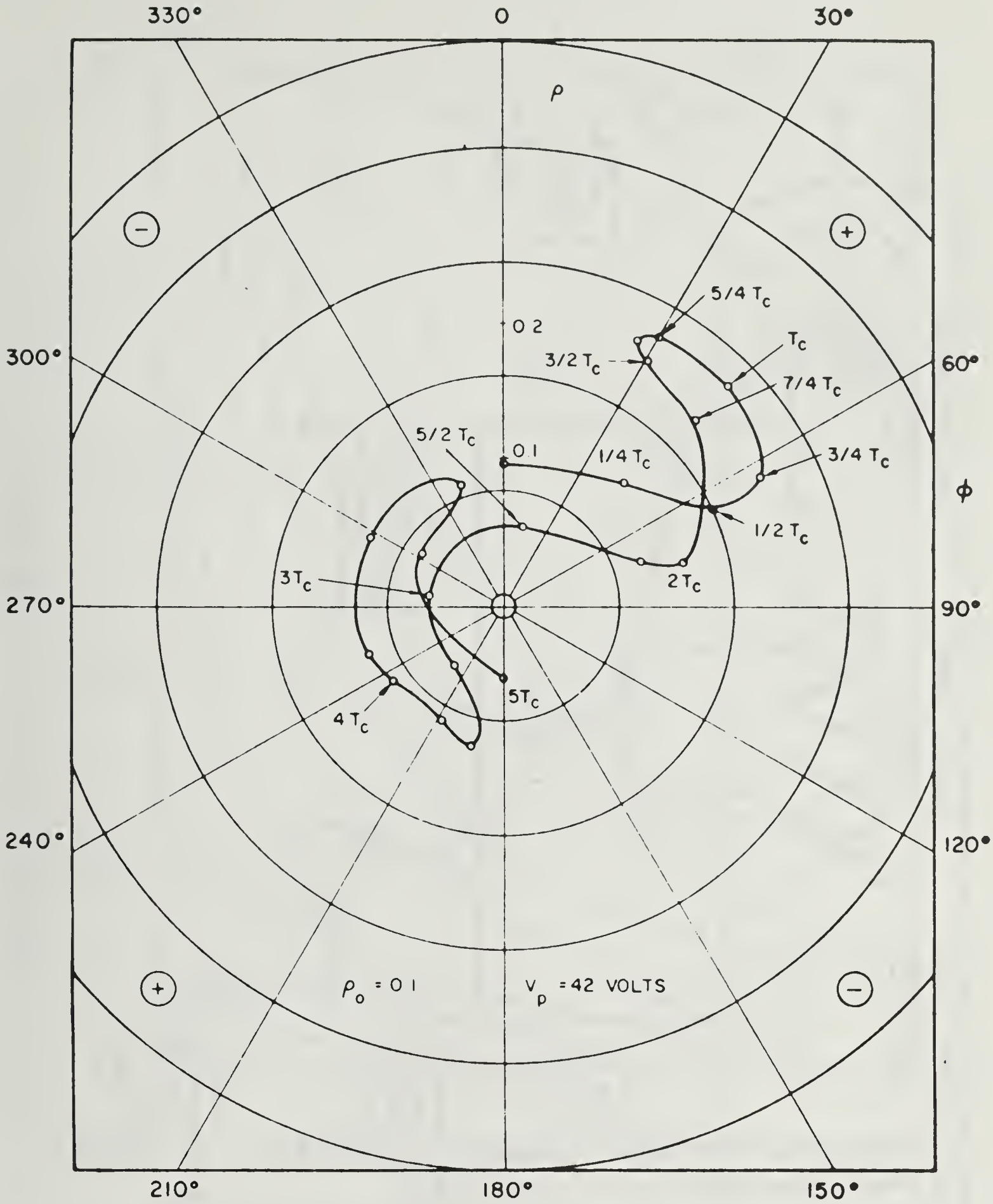

Fig. 2. CYCLOTRON-SYNCHRONOUS WAVE INTERACTION WITH A MEDIUM PUMP FIELD. (V_p = 42 volts)

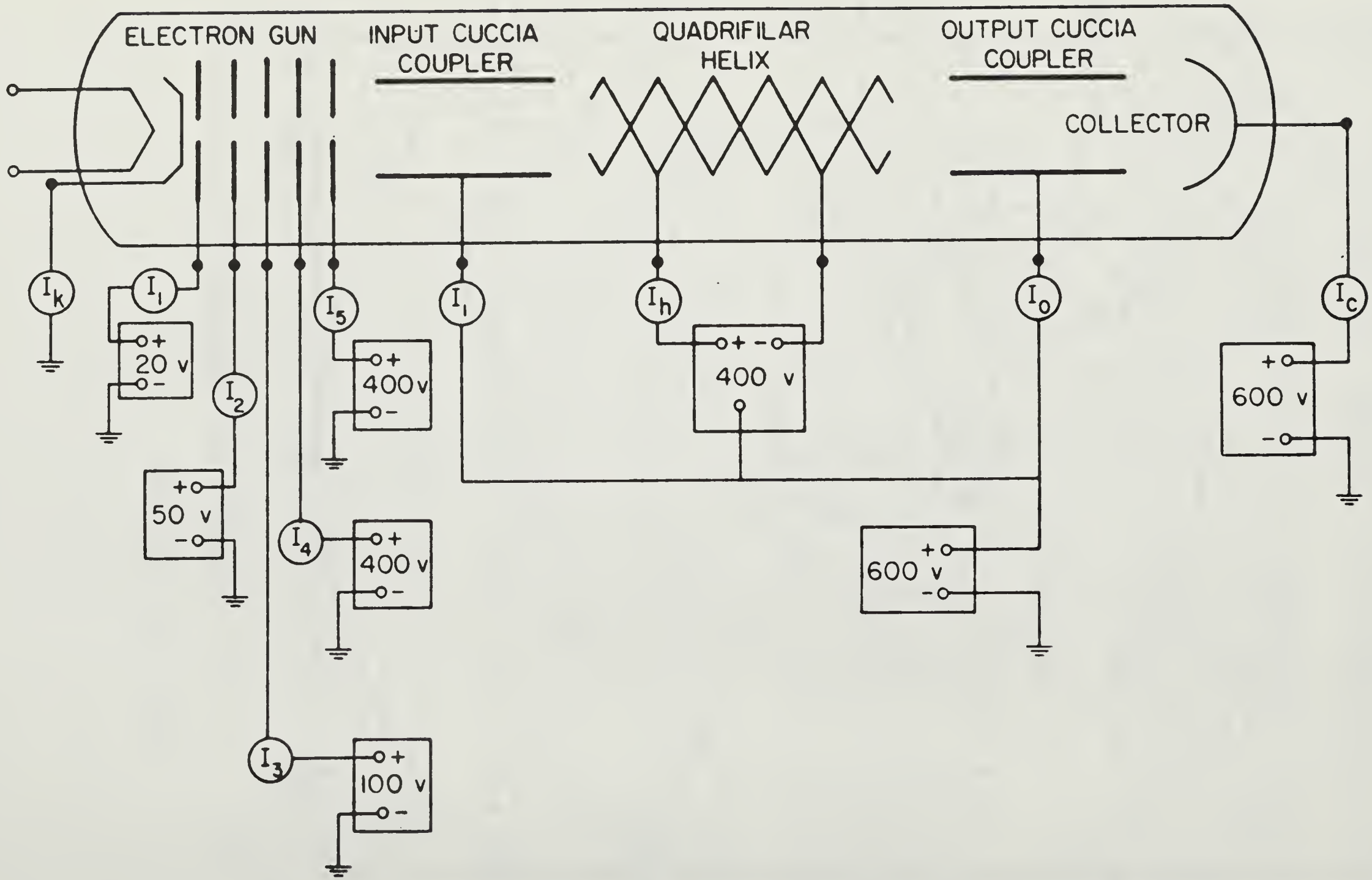

Fig. 4. EXPERIMENTAL SETUP FOR D-C BEAM TESTS.

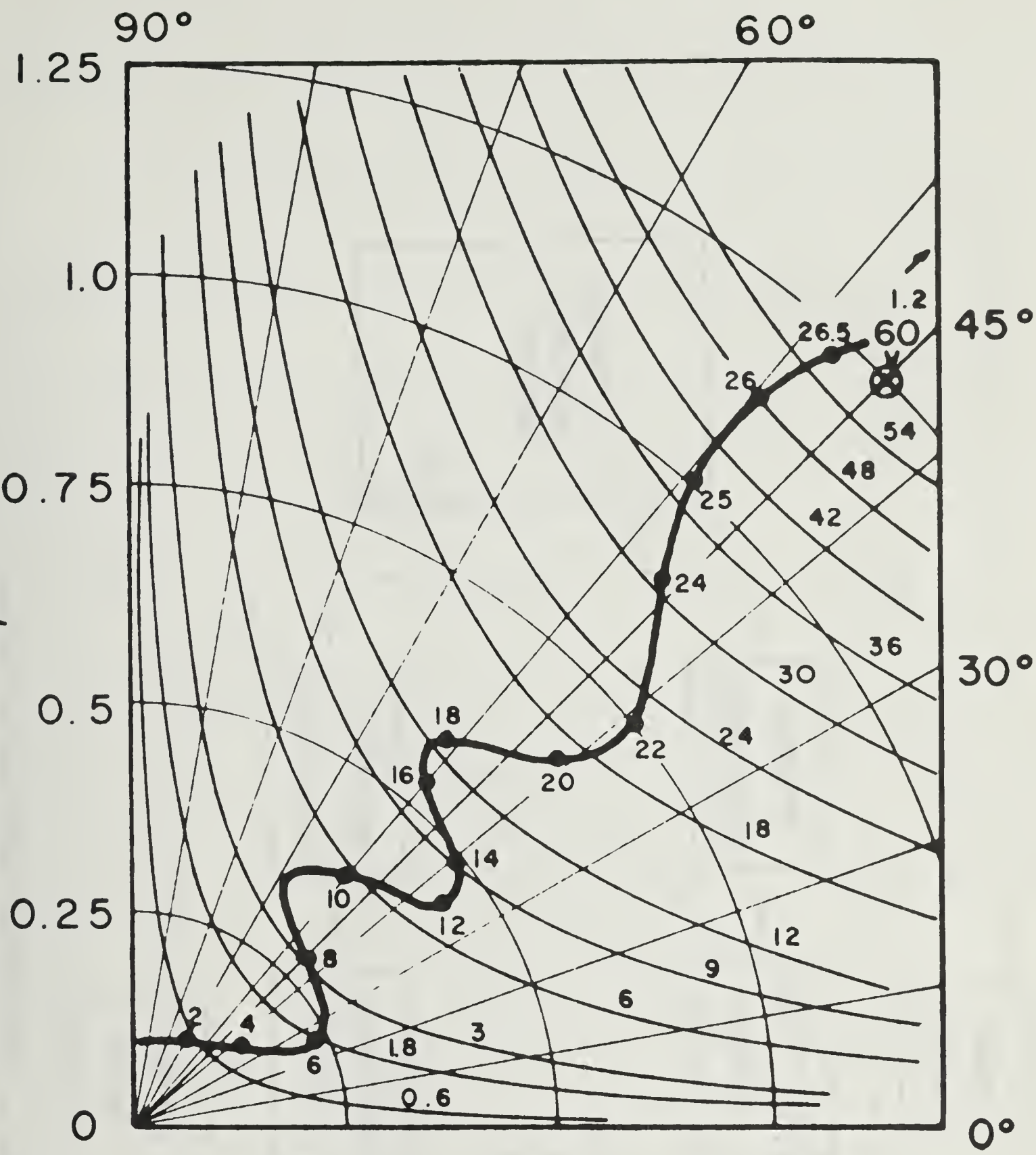

Fig. 3. CYCLOTRON-SYNCHRONOUS WAVE INTERACTION WITH A HIGH PUMP FIELD. (V_p = 53 volts)

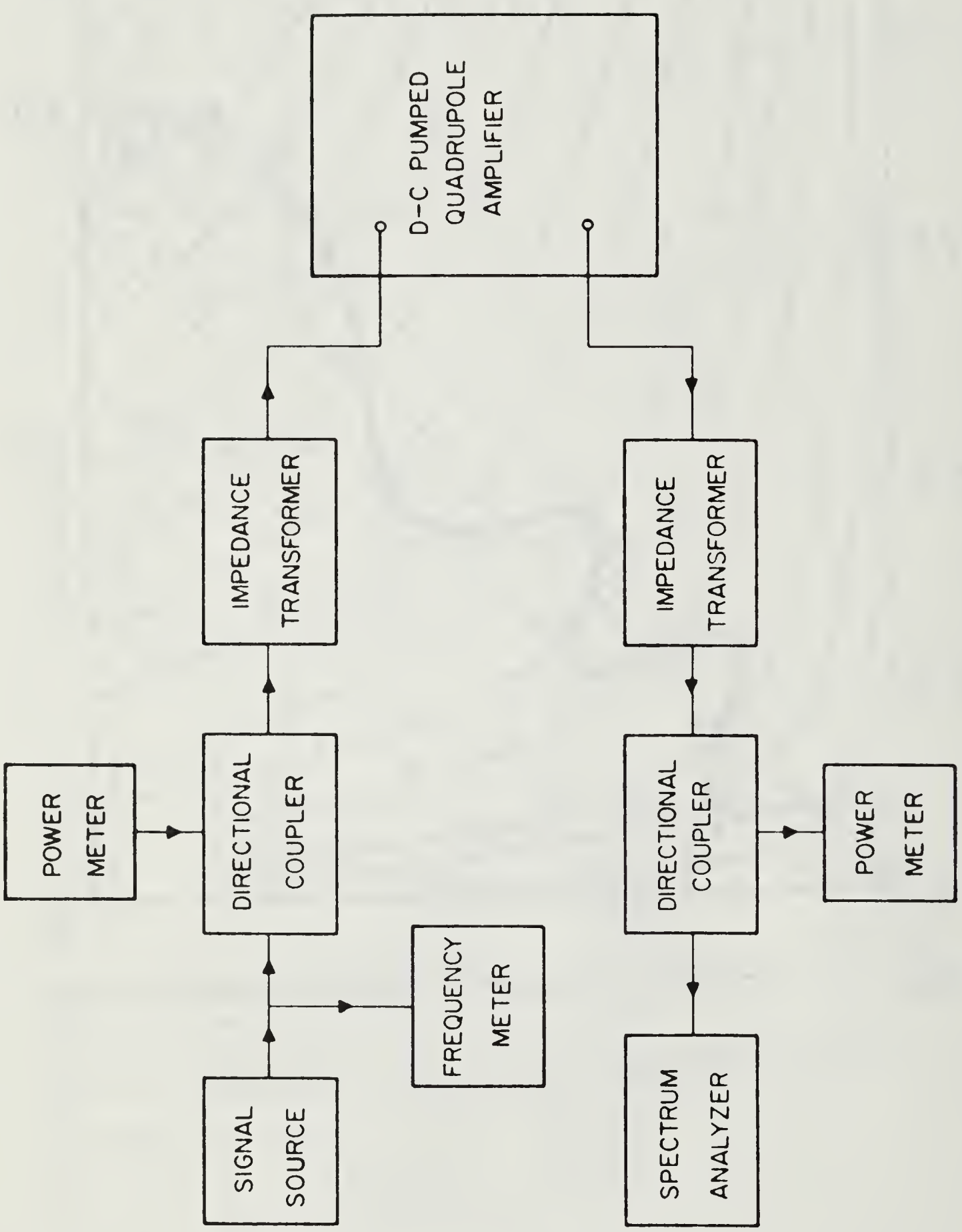

Fig. 5. EXPERIMENTAL SETUP FOR R-F TESTING.

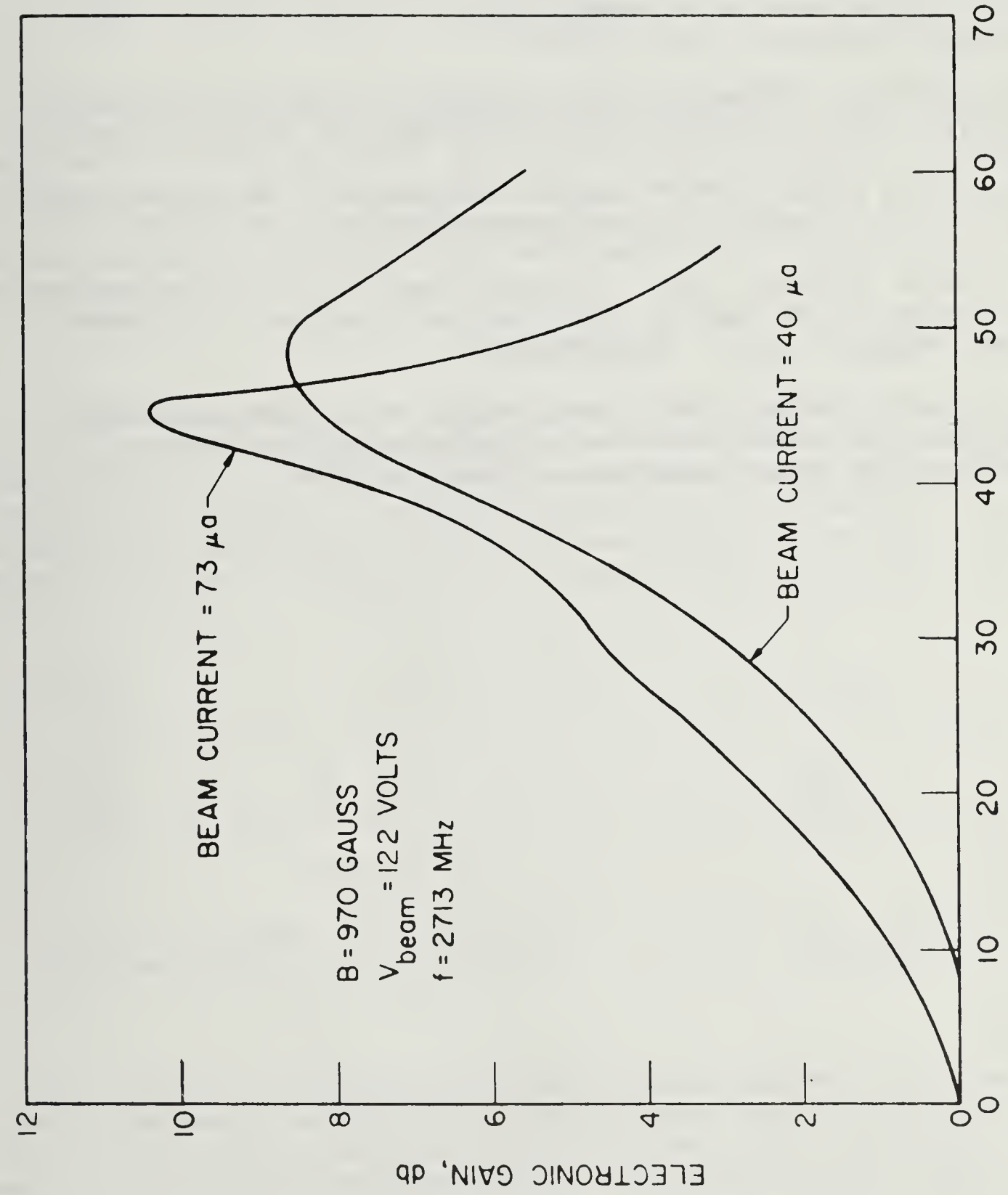

Fig. 6. S-BAND AMPLIFER GAIN VS. PUMP VOLTAGE FOR A CYCLOTRON-SYNCHRONOUS WAVE INTERACTION.

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IMMOBILIZATION OF DEXTRANASE WITH POTASSIUM, CUPRIC AND STANNIC SALTS OF DEXTRAN SULFATE

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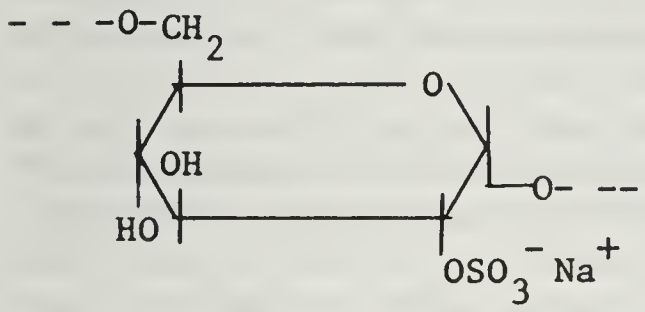
ABSTRACT

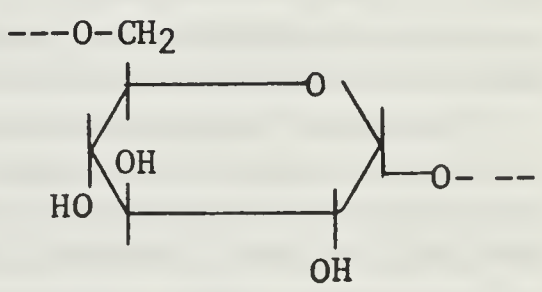
The enzyme dextranase can be used in dentistry to dissolve cariogenic dextranous carbohydrates on teeth. No literature previously has been found which describes the effects of dextran sulfate on dextranase activity. Recent experimentation revealed that four ionic forms of dextran sulfate combine with dextranase to form stable immobilized enzyme complexes. Dextranase activity is recovered when the complexes are redissolved in buffer solutions with dextrans. The stabilities of immobilized enzyme complexes were also investigated for exposure to heat and to ethanol.

INTRODUCTION

The enzyme dextranase (a - 1,6 - Glucan-6-glucanohydrolase E.C. 3.2.1.11) has been shown to be of value in removing cariogenic dextranous substances from human teeth (Keyes, 1971). No literature has been found which describes the effects of dextran sulfate (an analog of dextran) on dextranase activity. However, it has been demonstrated that dextranase can be immobilized by combining it with sodium dextran sulfate in a potassium phosphate buffer solution. A precipitate complex of dextranase and dextran sulfate can be obtained, stored, and redissolved in a buffer solution.



Molecular subunit of sodium dextran sulfate



Molecular subunit of dextran

Such a method of immobilizing dextranase is directly applicable to preventative clinical dentistry. Other existing methods for immobilizing dextranase may not be applicable since they incorporate biohazardous reagents (for examples see Epton, 1971). Dextran sulfate, however, seems to be a more desirable immobilizing reagent. It is less toxic than other reagents previously used and even has medicinal value as an anticoagulant and/or antiarteriosclerotic agent (Windholz, 1976). Furthermore, previous studies have demonstrated the neutraility of dextran sulfate on the growth and proliferation of many bacterial species (Potuznik, 1972). Thus, intraoral use of dextran

sulfate might not disturb bacterial populations found in the normal oral environment. The purposes of this research are to:

(a). develop quantities of chemically modified dextran sulfate to facilitate studies with dextranase immobilization and activity,

(b). and to investigate the effects of chemically modified dextran sulfate on the activity of dextranase.

The sodium ion of sodium dextran sulfate can be exchanged with other kinds of ions. It was of particular interest to prepare some dextran sulfates having ions of those metals used in dental amalgam. These metals are: silver, tin, copper, zinc and mercury (Young, 1969). In clinical dentistry, dextranase would be used intraorally, possibly in the presence of dental amalgam fillings. Hence, experimentation with amalgam components and dextranase together conveniently allows prediction of *in vivo* effects that amalgam has on dextranase activity.

MATERIALS AND METHODS

Commercial preparations of sodium dextran sulfate (M.W. =40,000) and bacterial dextranase were obtained from Sigma Chemical Company (St. Louis, Missouri). A method was devised for generating metal-ion dextran sulfates from sodium dextran sulfate. The overall procedure for the preparation of three dextran sulfates is shown in Figure 1. In summary, water soluble salts ($AgNO_3$, $CuSO_4$, and $SnCl_4$) were obtained for three of the five amalgam metals (silver, copper, and tin). Potassium dextran sulfate also was prepared using the water soluble salt, KNO_3 (Figure 1).

Each water soluble metal salt was dissolved in excess with the sodium dextran sulfate. In one case (stannic dextran sulfate) the excess metal ions produced an immediate precipitate. Ethanol (95%) was added dropwise until the solution became cloudy, heated to remove any phase separation, and cooled to precipitate the metal ion dextran sulfate. The precipitates were washed with cold 95% ethanol and dried in an Abderhalden pistol with charcoal and phosphorus pentoxide. All precipitates were redried after each of two washings with cold 95% ethanol. The refluxing solvent used in the pistol was acetone (b.p.56°C).

All chemical reagents and reactions in the production of silver dextran sulfate were shielded from sunlight by using glassware wrapped in aluminum foil. About 1% yield contrasts sharply with a 25% yield for potassium dextran sulfate, a 70% yield obtained for cupric dextran sulfate, and a 90% yield for stannic dextran sulfate.

The effects of potassium, cupric, and stannic dextran sulfates on dextranase activity and immobilization were studied. Measurements of dextranase activity were performed at room temperature using 0.10 M sodium phosphate buffer (pH 6) having 2%-5% w/v dextran substrates with an average molecular weight of 170,000. Dinitrosalicylate reagent was used to dye the isomaltose enzyme products. An isomaltose reference curve was used as a standard, and enzyme activity was quantified as moles of isomaltose produced per unit time (Janson, 1966). Absorbances were measured with a Bausch and Lomb Spectronic 20. The kinetic effects of potassium, cupric, and stannic dextran sulfate added to dextranase solutions are shown in Graph 1. When samples of reaction mixtures were removed for activity measurements, special care was taken to avoid sampling precipitates of dextranase-dextran sulfate complexes that settled in the glassware.

All enzyme reactions with silver dextran sulfate were shielded from sunlight by wrapping glassware in aluminum foil. However, when dinitrosalicylate was added to silver dextran sulfate solutions, an intense color change of the mixtures resulted which prevented a quantitative colorimetric determination for isomaltose. Consequently, the enzyme reactions with silver dextran sulfate could not be measured.

The stability of dextranase-dextran sulfate complexes was also investigated for heat exposure and a denaturant, ethanol. A quantity of 0.0002 milliequivalents of the three dextran sulfate salts (Figure 1) were each mixed with 35 enzyme units in 0.15 ml of water. The mixtures were centrifuged 45 minutes at 7000 r.p.m., and the precipitated pellets and supernatants were dried in

an Abderhalden drying apparatus for 75 minutes. Several solvents were used in the drying pistol to vary the temperature: ether (36°C), methylene chloride (42°C), acetone (56°C), and methanol (64°C). The subsequent dried materials were stored overnight in a desiccator at 5°C. The enzyme activity of each enzyme-dextran sulfate complex was measured using 0.10 M sodium phosphate buffer (pH 6) at 24°C with 2.35×10^{-4}M destran substrates. Results are shown in Graph 2.

To investigate the effects of ethanol on enzyme reaction mixtures, equal milliequivalents of each of the three dextran sulfates and equal enzyme units were mixed together in mixtures of ethanol and 0.10 M sodium phosphate buffer at pH 6 and 24°C with 2.35×10^{-4}M dextran substrates. The enzyme activity of each enzyme-dextran sulfate complex was measured. Results are shown in Graph 3. The maximum percentage of ethanol used in reaction mixtures was limited because volumes of reaction mixtures greater than 0.6% in ethanol rapidly caused fading of dinitrosalicylate color changes used to quantitate isomaltose.

RESULTS AND DISCUSSION

Graph 1 illustrates the kinetics obtained with the three dextran sulfates on the initial rate of dextranase activity. By measuring enzyme activity of the reaction mixtures at short time intervals (60 sec.), it was possible to investigate the effects of dextran sulfate on dextranase immobilization. As shown in Graph 1, solutions of free enzyme exhibited typical Michaelis-Menton kinetics. However, almost all solutions of dextran sulfate and dextranase initially retained a common rate of enzyme activity (fixed at about 3 millimole isomaltose produced per minute). Typical Michaelis-Menton kinetics were restored to immobilized enzyme solutions when sufficient substrate (more than 0.5 milliequivalents of dextran) was added.

The kinetic effects of sodium dextran sulfate on dextranase activity were nearly identical to the effects of potassium dextran sulfate (shown in Graph 1) when the same reagent quantities and experimental conditions were used. In other experiments, reaction mixtures that contained 76 enzyme units with dextran and dextran sulfate were sampled for activity measurements at 10 minute intervals for 120 or more minutes. By measuring enzyme activities at 10 minute intervals, the effects of sodium dextran sulfate on the enzyme activity were observed for longer time periods than those used to obtain results in Graphs 1-2 (at 60 or 90 sec. intervals for 10 or more min.).

Lineweaver-Burk plots of dextranase activities in the presence of sodium dextran sulfate revealed kinetics indicative of noncompetitive inhibition. The plots demonstrated that dextran sulfate possibly binds: (a) to non-catalytic sites on the enzyme molecule, (b) and to both free enzyme and enzyme-substrate complexes. However, true noncompetitive inhibition is defined as being irreversible. This is not the case here since a fully active enzyme (in terms of reaction rate) was regained when sufficient substrates were added to the reaction mixtures. This same activity was observed for Michaelis-Menton kinetics for solutions of enzymes immobilized with metal-ion dextran sulfates.

Thus, dextran sulfates possibly bind at one or several non-catalytic sites on the enzyme in solution. Polysaccharides such as dextran, cellulose, and agarose have been proposed as ligands for binding enzyme-immobilizing chemical groups (Biagioni, 1978). The dextran sulfates possess ionic sulfate groups that give the molecule an anionic charge. In this way, dextran sulfate may absorb to the enzyme by ionic associations. The use of equal milliequivalents of potassium, cupric, and stannic dextran sulfate resulted in differences in the enzyme activities recovered. As seen in Graphs 2 and 3, initial enzyme velocities recovered from experimental control reactions having free enzyme and enzyme immobilized with potassium dextran sulfate were 1.9 times greater than the velocities obtained from similar control reactions having enzymes immobilized with cupric dextran sulfate, and 1.4 times greater than the activities recovered from the enzyme-stannic dextran sulfate complexes. Consequently, the association of metal ions with dextran sulfate may affect enzyme activity. This suggests the cationic sites are important for immobilization and the retention of enzyme activity.

Several methods of enzyme immobilization involve physical entrapment and localization of enzymes in solution by unreactive compounds such as various starches and gel polymers (Guilbault, 1979). It is possible that dextran sulfate acts as a nonionic substance that immobilizes dextranase by physical entrapment of the enzyme. In separate experiments, dextranase and sodium dextran sulfate only, were added to 0.10 M potassium phosphate buffer at pH 6 with 0.5 M NaCl. No significant production of isomaltose was detected although precipitates of dextranase and dextran sulfate were formed. The absence of isomaltose production in these mixtures indicated the inertness of dextran sulfate to attack by dextranase. Nevertheless, adsorption to and/or physical entrapment of dextranase by dextran sulfate may constitute the immobilization process.

Activity rates measured from solutions of pre-heated, immobilized complexes were low compared to rates from solutions of pre-heated, free enzyme (Graph 2). Thus, thermal effects indicated that immobilized enzyme complexes at high temperatures destabilize the complexes and impede their retention of enzyme activity. This phenomenon also is observed for many kinds of immobilizing agents that destabilize enzymes above certain critical temperatures (Zaborsky, 1973).

Reaction rates also were measured from immobilized and non-immobilized enzyme solutions that contained up to 0.12% ethanol by volume (Graph 3). Ethanol was previously used to precipitate dextran sulfate salts (Figure 1) in aqueous solutions. However, the ethanol solutions used greater than 0.05% in ethanol did not greatly alter immobilized or freee enzyme activity. Thus, immobilized and free dextranase remain stable and retain about 95% of their original activity in ethanol solutions and may continue to do so up to the 0.6% ethanol limit. Since ethanol initiates the precipitation of dextran sulfate from aqueous solutions, it might be possible to develop an ethanol reagent to precipitate immobilized complexes from solution. Such a reagent could conceivably be used without causing loss of enzyme activity in recovered complexes.

SUMMARY

Dextranase (a - 1,6 - Glucan-6-glucanohydrolase E.C. 3.2.1.11) was immobilized with dextran sulfate anions that were combined with K^{+}, Na^{+}, Cu^{+2}, and Sn^{+4} ions. Enzyme studies were performed on the immobilized dextranase-dextran sulfate complexes.

All three dextran sulfates were found to cause stabilized enzyme activity as compared to activity of non-immobilized enzyme. The kinetics of the three immobilized dextranase complexes were similar under the experimental conditions used. The stabilizing effects of dextran sulfate on dextranase activity were reduced when immobilized enzyme complexes were heat treated up to 64°C. Non-immobilized enzyme subjected to the same treatments retained greater activity than did immobilized enzyme. Although ethanol insolubilizes dextran sulfate, little difference was detected in enzyme activities of immobilized and non-immobilized enzyme solutions that contained small amounts of ethanol.

Dextran sulfate probably immobilizes dextranase in solution by adsorption to (by ionic association) and/or entrapment of the enzyme.

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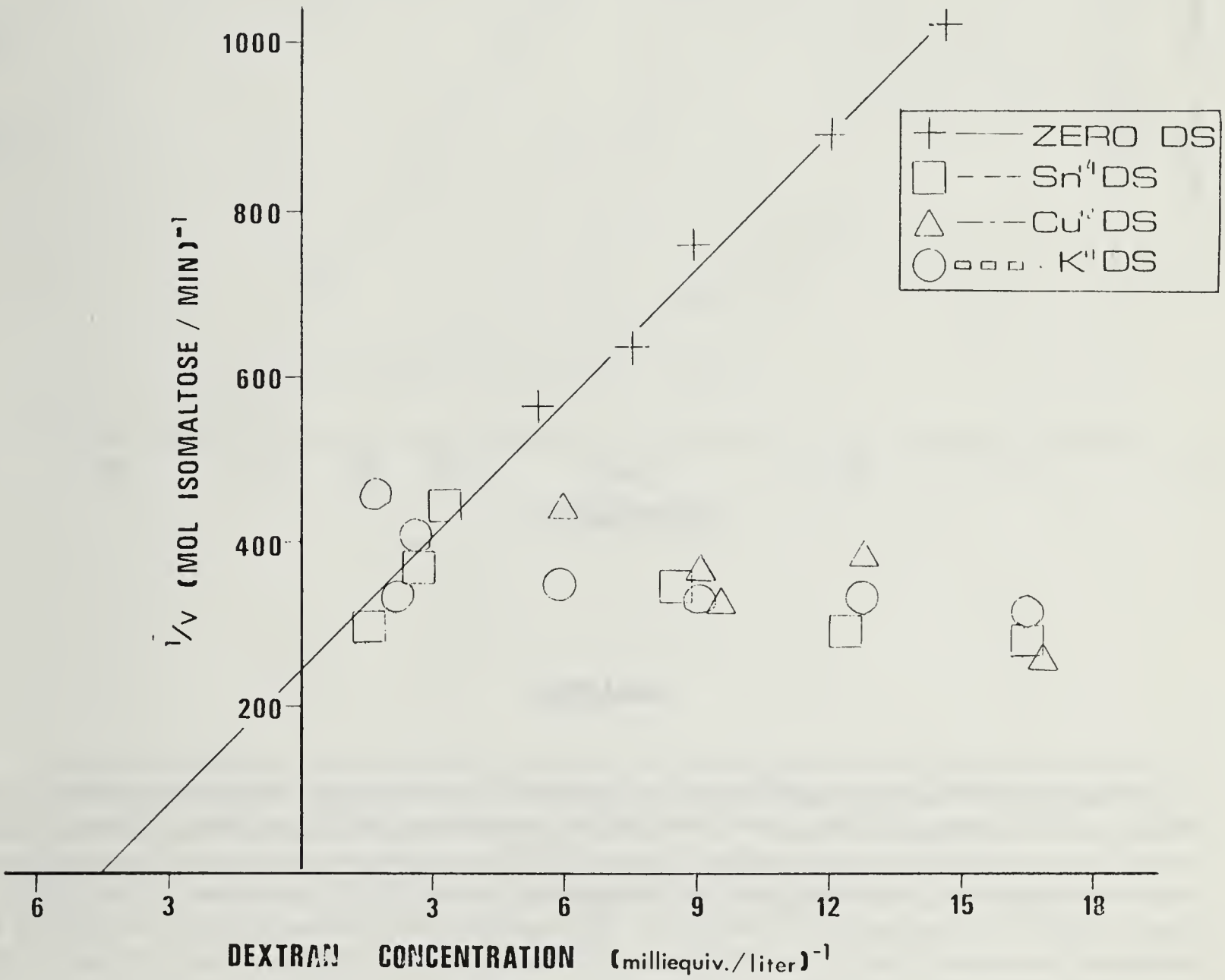
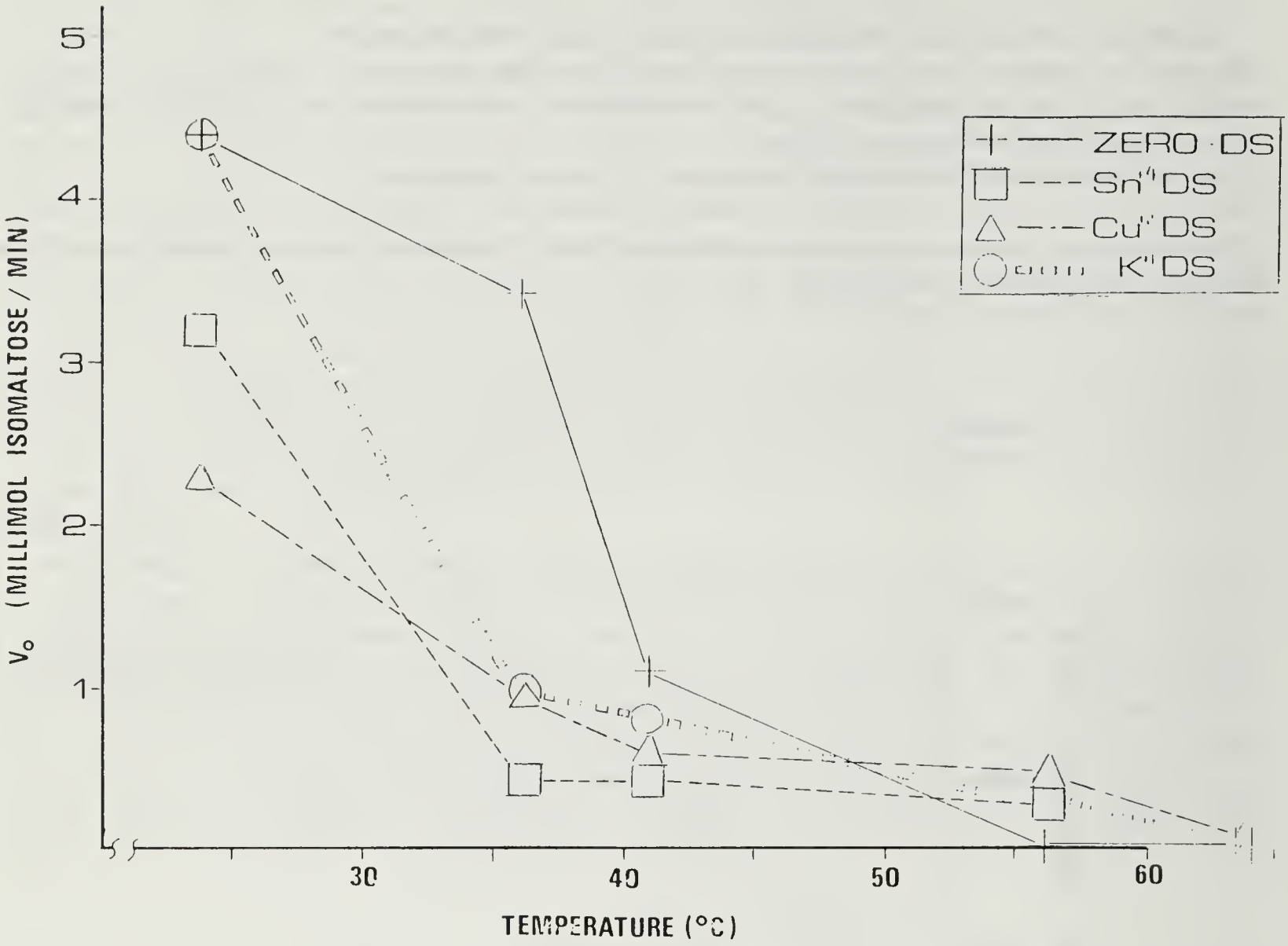


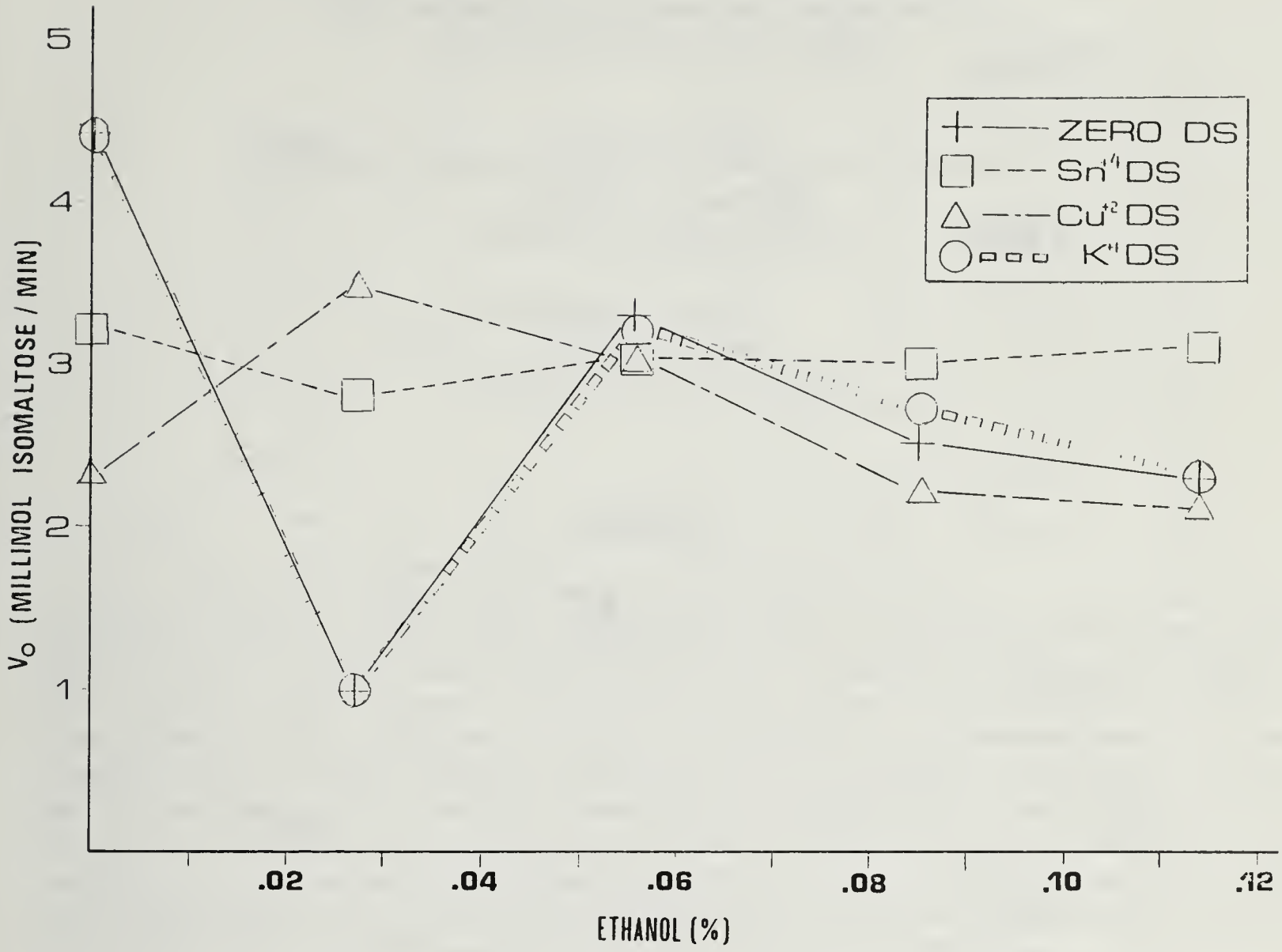
GRAPH 1

Lineweaver-Burk plots of hydrolysis of dextrans to isomaltose by bacterial dextranase in the presence of 0.015 milliequivalents of stannic, copper, and potassium dextran sulfate. 76 enzyme units of bacterial dextranase (Sigma Chemical Co.) in 12 ml of 0.10 M sodium phosphate buffer at pH6 and 24°C with dextran substrates were used in each case. Measurements of enzyme activity were made on samples taken from reaction mixtures at 60 sec. intervals for 10 or more minutes (K_m apparent = 0.23 millieq.). Similar reaction mixtures containing all the above components except dextran substrates revealed no detectable isomaltose production.



GRAPH 2

Plots of immobilized dextranase activity vs. temperature at which immobilized complexes were dried. 2×10^{-4} milliequivalents of the dextran sulfate were mixed with 35 enzyme units in 0.15 ml water. The mixture was centrifuged for 45 min. at 7000 r.p.m. Resulting pellets and supernatants were dried together at the boiling point temperatures of ether (36°C), methylene chloride (42°C), acetone (56°C), or methanol (64°) for 75 min. The resulting materials were stored overnight in a desiccator (containing $CaCl_2$ and P_2O_5) at 5°C. Measurements of enzyme activity were then made using 7 m1 of 0.10 M sodium phosphate buffer at pH6 and 24°C with 2.35×10^{-4} M dextran substates. Measurements were made at 90 sec. intervals for 10 or more min.



GRAPH 3

Plots of immobilized dextranase activity vs. volume percentage of ethanol in reaction mixture. 2×10^{-4} milliequivalents of the dextran sulfate were mixed with 35 enzyme units in 7 m l of 0. 10 M sodium phosphate buffer at pH6 and 24°C with 2.35×10^{-4} M dextran substrates and 0.0285%, 0.057%, 0.056%, and 0.1140% ethanol by volume. Measurements of enzyme activity were made on samples taken from reaction mixtures at 90 sec. intervals for 10 or more min.

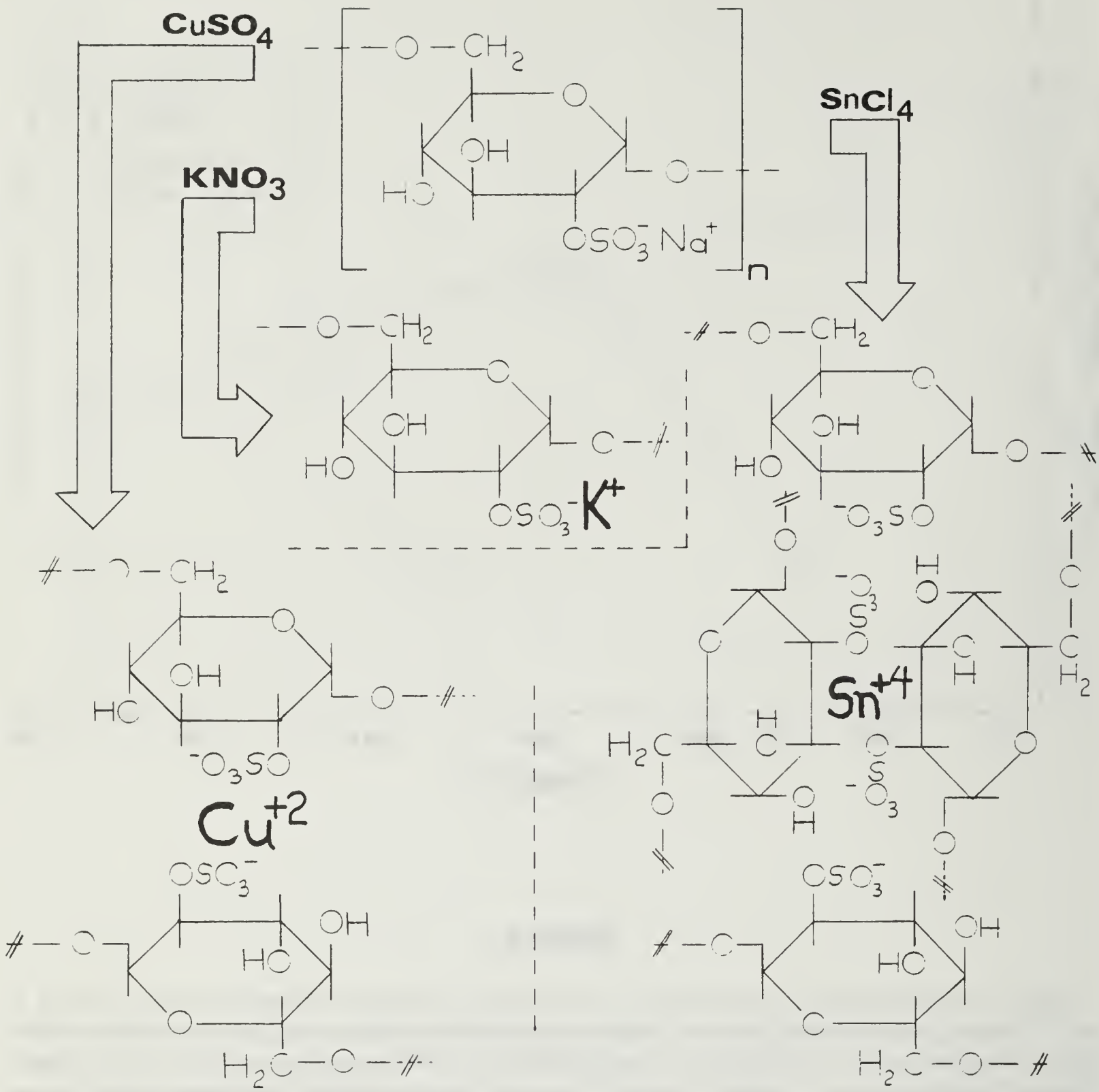


FIGURE 1

Reaction schemes involved in generating dextran sulfate derivatives.

EFFECTS OF COPPER SULFATE APPLICATION ON DIEL DISSOLVED OXYGEN AND METABOLISM IN THE FOX CHAIN OF LAKES

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ABSTRACT

In-situ measurements of diel dissolved oxygen and metabolism were made of the euphotic zone of treatment and control bays in the Fox Chain of Lakes in northeastern Illinois during the application of the algacide, copper sulfate. Significant (>1 mg/1) diurnal changes in dissolved oxygen were seen in all fourteen diurnal measurements reported here. Both dawn and dusk dissolved oxygen were slightly lower in the bay being treated by the algacide. Respiration was significantly higher in the treated bay, probably due to decomposition of dead algae cells. No significant decrease was determined for gross primary productivity during the study period. The aquatic community apparently recovered rapidly from the copper sulfate stress. Overall primary productivity at the experimental and control bays compared well with some productivity studies made in other shallow aquatic systems although areal primary productivity was probably limited by the shallow depths and turbid waters in the bays studied.

INTRODUCTION

The Fox Chain of Lakes (Figure 1) are a series of nine natural lakes that have formed along the Fox River in Lake and McHenry counties in northeastern Illinois. The major inflows of water and nutrients are contributed from the Fox River as it flows from Wisconsin and the surface levels of the lakes are partially controlled by a down-stream dam at McHenry. The lakes are an important recreation area for northeastern Illinois although they have recently shown signs of excessive eutrophication. Fish kills have been documented by Muench (1964) while studies by the U.S. Public Health Service (1963) and the Illinois State Water Survey (1966) described the eutrophic conditions of several of the lakes.

A comprehensive limnological study of the Chain by Kothandaraman *et al.*(1977), summarized by Kothandaraman and Evans (1978a,b,c), determined water quality and nutrient budgets for the lakes and gave recommendations for control of the symptoms of eutrophication. The application of copper sulfate to control algal blooms was attempted in the summer of 1977 by the Illinois State Water Survey in Mineola Bay of Fox Lake (see Figure 1). Three applications were made at loading rates of 6.0 kg/ha each, the equivalent of 1 mg/1 copper sulfate for the top 2 feet of water. Descriptions of the chemical treatments are given in Kothandaraman *et. al.* (1978).

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[1]Field work done while at Pritzker Department of Environmental Engeering, Illinois Institute of Technology, Chicago, Illinois 60616.

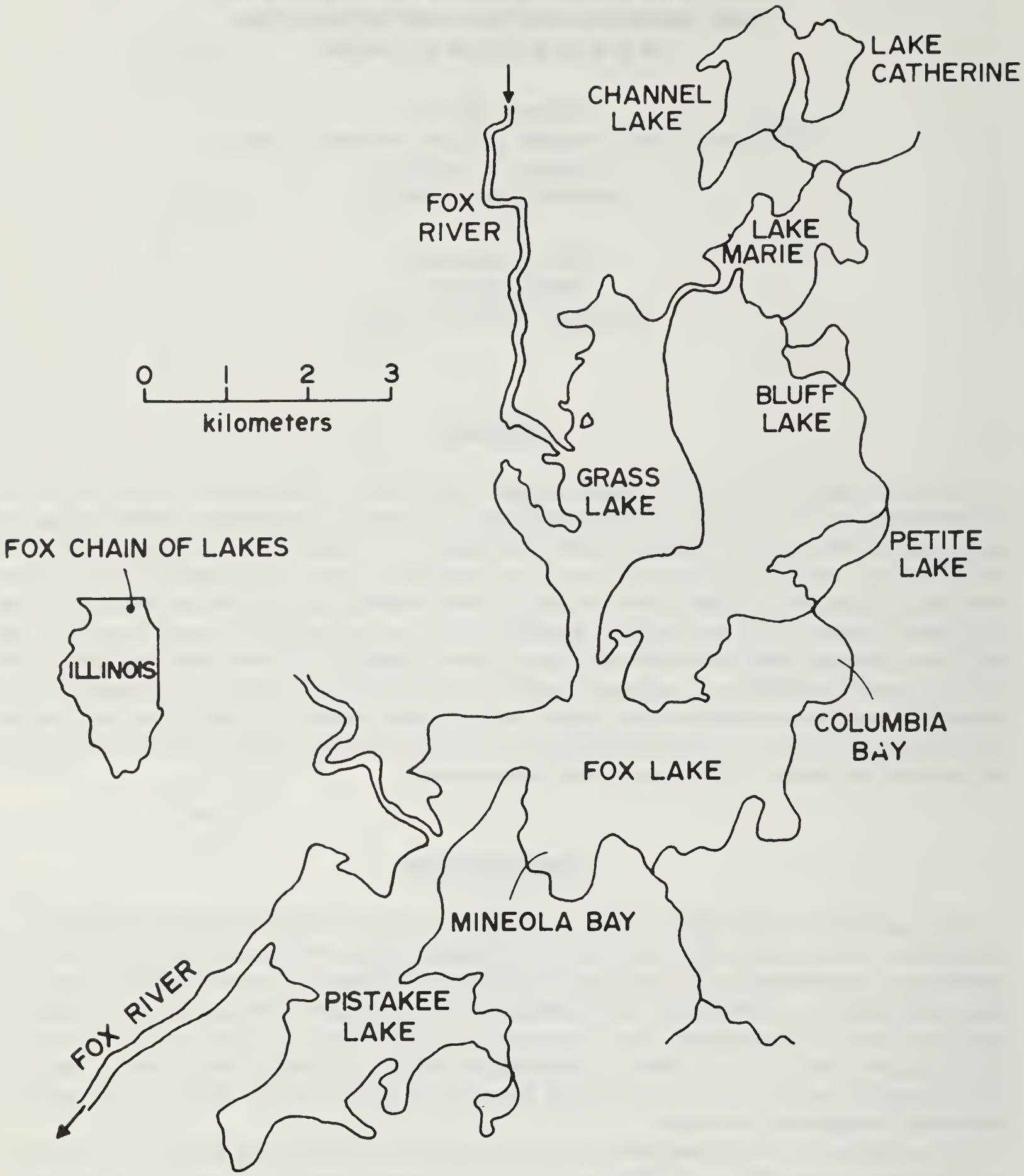

Figure 1. Fox Chain of Lakes Study Area in northeastern Illinois.

This study presents the results of free-water diel dissolved oxygen measurements in Fox Lake to determine the effects of the copper sulfate treatments on overall euphotic zone metabolism. Diel or diurnal dissolved oxygen methods in free water have frequently been used to measure aquatic ecosystem metabolism in streams (Odum, 1956, 1957; Duffer and Dorris, 1966; Owens, 1969), estuaries (Odum and Hoskin, 1958; Nixon *et al.*, 1976; McKellar, 1977) and lakes and reservoirs (Welch, 1968; Manny and Hall, 1969; Eley, 1970). The use of free water measurements rather than incubation samples overcomes several problems of isolating samples in bottles. Reduction of turbulence in bottles may inhibit metabolism, glass surfaces may serve as a good substrate for bacteria and algae, and some light may be absorbed by using incubation samples. The major limitations of the open water method include its lack of sensitivity in oligotrophic waters, not a problem in the Fox Chain of Lakes, and the uncertainty of the necessary oxygen diffusion corrections. Hall and Moll (1975) summarize many of these advantages and disadvantages.

MATERIALS AND METHODS

Sampling stations were located in Mineola Bay (treatment site) and in Columbia Bay (control site) on Fox Lake (Figure 1). We chose Columbia Bay, about 3km from Mineola Bay, as the control site in our study despite the use of Fox Lake itself as a control by Kothandaraman *et al.* (1978). We felt that their control site was not properly chosen because 1) it was too close to the treatment (about 300 m in some cases), 2) it was not in waters with similar ''bay-like'' shoreline protection from waves and other turbulence, and 3) flow-through characteristics were probably dissimilar for their experimented and control sites.

Dissolved oxygen was measured by the Azide modification of the Winker titration (A.P.H.A.,1975). Replicate 125 ml samples were obtained just below the surface and at one meter depth at the treatment and control sites (8 samples per run) with a Kemmerer sampler. Solar radiation was measured by a recording pyroheliograph. Secchi disk measurements were taken to estimate euphotic zone depth according to the relationship (Cole, 1975):

$$d_{ez} = 2.4\ d_{sd}$$

where,

d_{ez} = euphotic zone depth, m
d_{sd} = Secchi disk reading, m

Chlorophyll *a* was determined by the spectrophotometric method described by Strickland and Parson (1968) and was uncorrected for pheophytin pigments.

Primary productivity and respiration were measured by an abbreviation of the diel oxygen curve method of Odum and Hoskin (1958). The abbreviated method involves the use of dawn-dusk-dawn dissolved oxygen measurements rather than more frequent sampling. Simultaneous measurements by the abbreviated and full diel methods on six occasions during the study period in the Chain of Lakes showed no significant differences in productivity calculations ($P < 0.05$). This was also found to be the case by McKellar (1977).

The diel calculations were corrected for oxygen diffusion to or from the atmosphere by means of measurements of diffusion by a floating plastic dome (Copeland and Duffer, 1964). An average diffusion coefficient of 0.65 g O_2/m^2-hr @ 0% saturation from four measurements was used for correction. No differences were found in the conclusions mentioned below using the entire range of diffusion coefficients measured during the study.

An implicit assumption with the diel oxygen method for lakes is that the station being sampled is well mixed with surrounding waters which are also displaying similar oxygen patterns.

Figure 2 shows results from a typical diurnal patterns of dissolved oxygen in the control site; the surface oxygen increases by 5 to 6 mg/1 during daylight. This range suggests that the diel oxygen method is sensitive enough for productivity measurements in this body of water; measurement of dissolved oxygen by Winker titration can generally achieve repeatability of 0.1 mg/1.

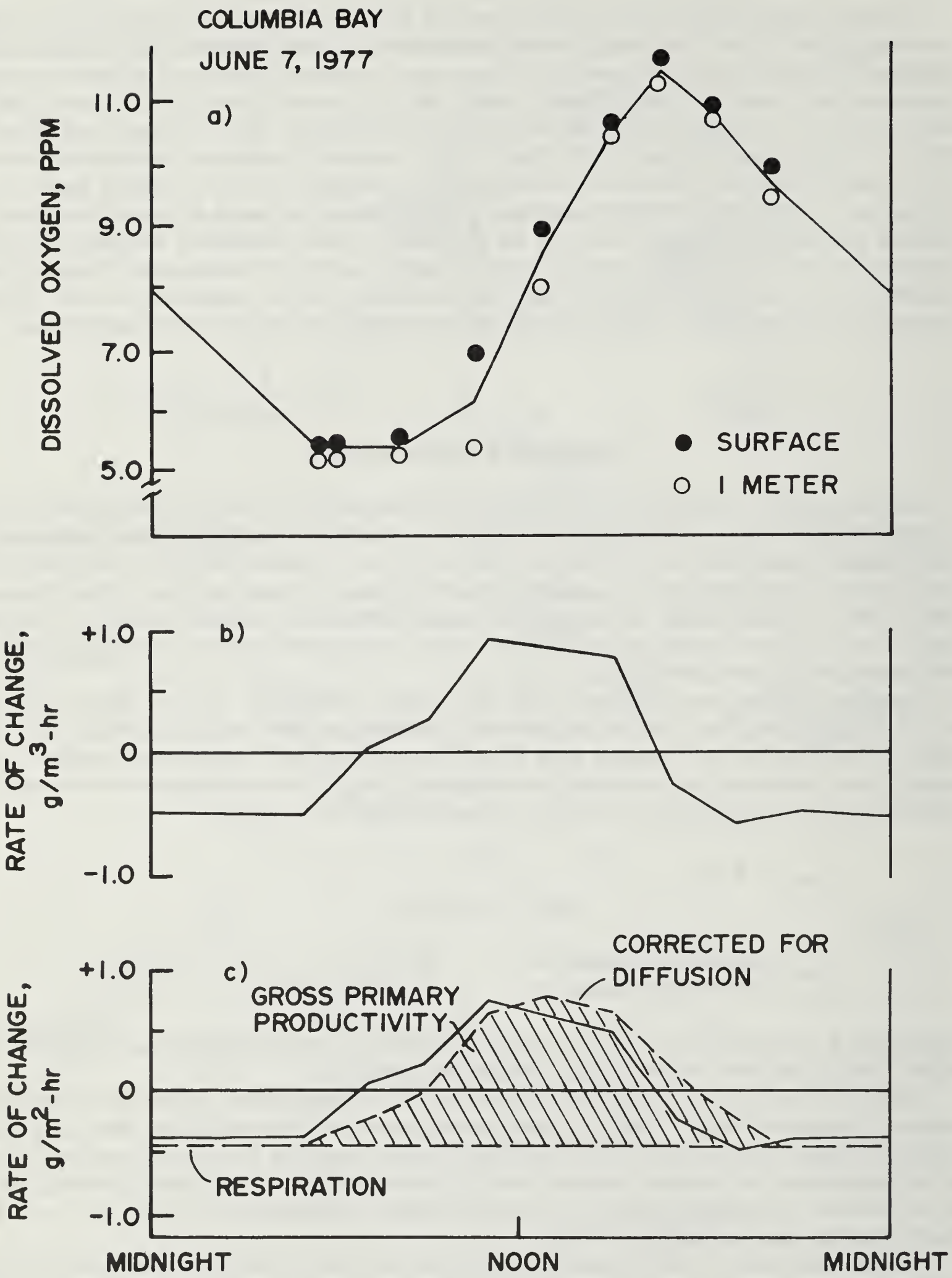

Figure 2. Example of calculation of euphotic zone metabolism on Columbia Bay showing a) diurnal change of dissolved oxygen, b) rate of change in oxygen per unit volume, and c) rate of change of oxygen per unit area of euphotic zone showing curves corrected and uncorrected for oxygen diffusion.

RESULTS AND DISCUSSION

Diel Oxygen Changes

The dawn-dusk-dawn dissolved oxygen measurements made in both Mineola bay ($CuSO_4$ treatment) and Columbia Bay (control) are given in Table 1. Diurnal differences of at least 1 mg/1 were seen in all cases and often differences were much higher. Significant productivity continued in Mineola Bay during the copper sulfate treatment even though some measurements were made within two days after application. Both dawn and dusk dissolved oxygen was lower in the treatment site than in the control site during the treatments with dawn readings averaging 0.5 mg/1 lower and dusk readings averaging 1.0 mg/1 lower. Dissolved oxygen at dusk continued to be 0.7 mg/1 lower in the treatment bay well after (2 months) the treatment suggesting that the effect might be prolonged.

Kothandaraman and Evans (1978a) report epilimnitic dissolved oxygen in Fox Lake in the summer of 1975 to range from about 6.5 to 9.0 mg/1, within the range seen by us in 1977 in both bays. However their study does not indicate if the dissolved oxygen measurements were taken at the same time of the day. This represents a significant omission for a study on the lake that often has greater diurnal changes in dissolved oxygen than the seasonal range given by Kothandaraman and Evans (1978a).

Euphotic Zone Metabolism

Dissolved oxygen, gross primary productivity, respiration, P/R ratios, chlorophyll *a* and Secchi disc transparency are compared for Mineola Bay and Columbia Bay in Figure 3 and Table 2. Paired t-tests were used to evaluate the results. Data for the entire summer were used for these statistical analyses because it appears from Table 1 that the copper sulfate applications suppressed algal bloom for the entire growing season. The production and respiration results were evaluated on both an areal basis ($g\text{-}O_2/m^2\text{-day}$) and a volume basis ($g\text{-}O_2/m^3\text{-day}$).

Productivity values were not significantly different ($P < 0.05$) between Mineola (treatment) and Columbia (control) Bays on either basis. The only noticeable decrease in productivity due to copper sulfate was seen approximately one week following the third treatment when the control bay productivity was 3.2 $g\text{-}O_2/\ m^2$- day while the treatment bay value was 0.6 $g\text{-}O_2/m^2$- day. Full recovery of gross primary productivity in Mineola Bay (treatment) was seen in 10 to 14 days after this last treatment. We observed a green scum coating the water surface for several days following the third treatment.

Community respiration in the treated bay was significantly higher than in Columbia Bay during the study period on both an areal and volume basis (Table 2). This would be an expected effect of the copper sulfate treatment. When the algae die and microbial decomposition commences, the microbial oxygen demand of the community increases. Respiration values were similar only immediately following the first and third copper sulfate treatments. Apparently, the heterotrophic microbial community is stressed along with the algal community immediately following copper sulfate application. More detailed follow-up on the third treatment shows that the community respiration of the treated bay increases dramatically over the control as microbial decomposition is accelerated, probably due to the presence of the dead algal cells.

P/R (productivity/respiration) ratios were compared for the treated and control bays. P/R ratios were significantly lower in Mineola Bay, reflecting the greater degree of heterotrophy in the treated bay. The behavior of the P/R ratio following the third copper sulfate application is of interest. An algal bloom occurred in the control bay on July 29 with a dusk dissolved oxygen value of 12.4 mg/1, the highest seen in the study; a very high P/R ration of 2.6 was calculated for that date. The higher respiration seen at the treatment bay during this time coupled with a slightly lower productivity prevented the dissolved oxygen from going beyond 10 mg/1 at dusk. The P/R ratio for the treatment was accordingly much lower at 0.9.

Table 1. Dawn-Dusk-Dawn Dissolved Oxygen in Mineola Bay and Columbia Bay, Fox Lake During Study Period. Dates of Copper Sulfate Application to Mineola Bay Are Also Given.

Date	Solar Radiation, kcal/m^2-day	Dissolved Oxygen, mg/l[1] Mineola Bay ($CuSO_4$)	Columbia Bay (Control)
June 2		COPPER SULFATE APPLICATION	
June 7-8	4982	6.5/10.0/6.2	6.4/10.0/6.2
June 27		COPPER SULFATE APPLICATION	
June 29-30	5706	5.0/7.8/4.7	5.6/9.8/6.2
July 19		COPPER SULFATE APPLICATION	
July 21-22	3363	4.7/7.2/5.4	6.1/6.9/5.1
July 26-27	4684	5.7/7.7/7.4	6.2/10.0/7.7
Average During Treatment	4684	5.5/8.2/5.9	6.1/9.2/6.3
		POST APPLICATION PERIOD	
Aug. 17-18	2938	5.6/7.0/5.8	5.4/7.4/5.6
Aug. 24-25	4386	6.2/9.0/6.3	6.5/9.8/7.0
Sept. 3-4	3662	5.7/7.1/6.1	6.3/7.9/6.7
Average After Treatment	3662	5.8/7.7/6.1	6.1/8.4/6.4

[1]Dissolved oxygen values are averages of two surface and two 1 m samples at Dawn/Dusk/Dawn.

Table 2. Comparison of Field Measurements Between Treatment and Control Bays for Copper Sulfate Treatment.

Parameter	Units	Mean Value Treatment	Control	Percent Difference
Less in treated bay*				
Productivity/respiration		0.5	1.0	−50
dissolved oxygen (dawn)	mg O_2/1	5.7	6.5	−12
dissolved oxygen (dusk)	mg O_2/1	7.8	9.4	−17
Greater in treated bay**				
respiration (areal)	g O_2/m^2-day	7.0	4.9	43
respiration (volumetric)	g O_2/m^3-day	11.1	7.7	44
No significant difference				
productivity (areal)	g O_2/m^2-day	3.8	4.2	−10
productivity (volumetric)	g O_2/m_2^{-3}-day	5.6	6.4	−12
Secchi disc	centimeters	25	25	0
chlorophyll *a*	mg chlorophyll/m^3	254	263	−3
assimilation ratio	g oxygen/g chlorophyll-hr	1.7	1.4	21

* significantly less in treated bay ($P<0.05$)
** signficiantly greater in treated bay ($P<0.05$)

Transparency and Chlorophyll

Secchi disc measurements are also given for treated and control bays in Figure 3. There was no significant difference between the bays. Secchi disc transparency decreased in both bays after late July, when peak algal blooms would be expected. After the third treatment, the transparency in Mineola Bay (treatment) decreased from 34 to 20 cm while the control bay readings decreased from only 30 to 25 cm. This difference was due to the dead algal scum observed after this treatment. Kothandraman and Evans (1978a) found a range of 15 to 53 cm for Mineola Bay in 1975 and Kothandraman *et al* (1978) found no differences in Secchi disk readings between the treatment site and their control.

Samples were collected for chlorophyll *a* beginning July 21 (Figure 3 and Table 2). There were no significant differences in concentrations for treated and control bays. These results do not necessarily show that there was no reduction in viable algal cells after treatment because results were uncorrected for phaeopigments, chlorophyll degradation products, which may have been a significant percentage of the measured chlorophyll *a*. Chlorophyll *a* concentrations decreased in late August indicating that the algal bloom was decreasing from the summer maximum at this time. Kothandaraman *et al* (1978) found that algal counts dropped significantly after every chemical treatment but that the algal populations recovered within a few days. Our data and theirs, taken together, indicate that phytoplankton biomass was not significantly reduced over long periods by the copper sulfate treatment.

Aquatic Metabolism Comparison

The aquatic metabolism measurements made in this study are compared with other studies that have employed the diel oxygen method on lentic waters (Table 3). Our ranges compare well with those found by Nixon *et al.* (1976) in a shallow salt marsh embayment during summer measurements and with a study of an estuarine bay in Florida (McKellar, 1977). The annual averages found by Welch (1968) for a small Georgia pond could also easily represent the approximate annual values for the Fox Chain of Lakes. Eley (1970) measured very high metabolism values in a eutrophic reservoir in Oklahoma while Manny and Hall (1968) reported higher productivites in Lake Michigan. Both of these studies, however, are based on assumptions of euphotic zone depth that probably lead to overestimations.

Our assumption of determining euphotic zone by multiplying the Secchi disk reading by 2.4 may lead to slightly low metabolism values. Cole (1975) describes a multiplication factor of as high as 5.0 for highly turbid waters. It is possible for the calculated euphotic zone to actually exceed the depth of the bays which would lead to an overestimation of areal productivity. However, our assumptions appear to be valid for the shallow waters in the bays studied here. Our average calculated euphotic zone is 0.6 m while Kothandaraman *et al.* (1978) report an average depth of Mineola Bay of about 1.5m.

A comparison is also given with diel oxygen measurements made in two other lakes in the Fox Chain of Lakes in Table 3. Measurements in Bluff Lake, discussed by Kaltenborn (1978), gave consistently higher areal productivities than either of the bays in this study. This may also be due to assumptions about euphotic zone as Bluff Lake had higher water transparency. Solar efficiencies in the Fox Lake bays were reasonable, however, ranging from 0.05 to 0.7 percent of total insolation while a maximum of 2.2 efficiency was seen in Bluff Lake. Maximum solar efficiency in aquatic systems is accepted to be around 2% (Odum, 1971). More accurate measures of euphotic zone depth are obviously needed for future studies such as these.

Our studies here, as well as other measurements made in Illinois and elsewhere show the applicability of using the open water diel oxygen method to assess metabolism of certain aquatic systems. Widespread use of this method in Illinois would provide a useful method for comparing ecosystem function of a wide range of natural and managed bodies of water and could aid in classification and management schemes.

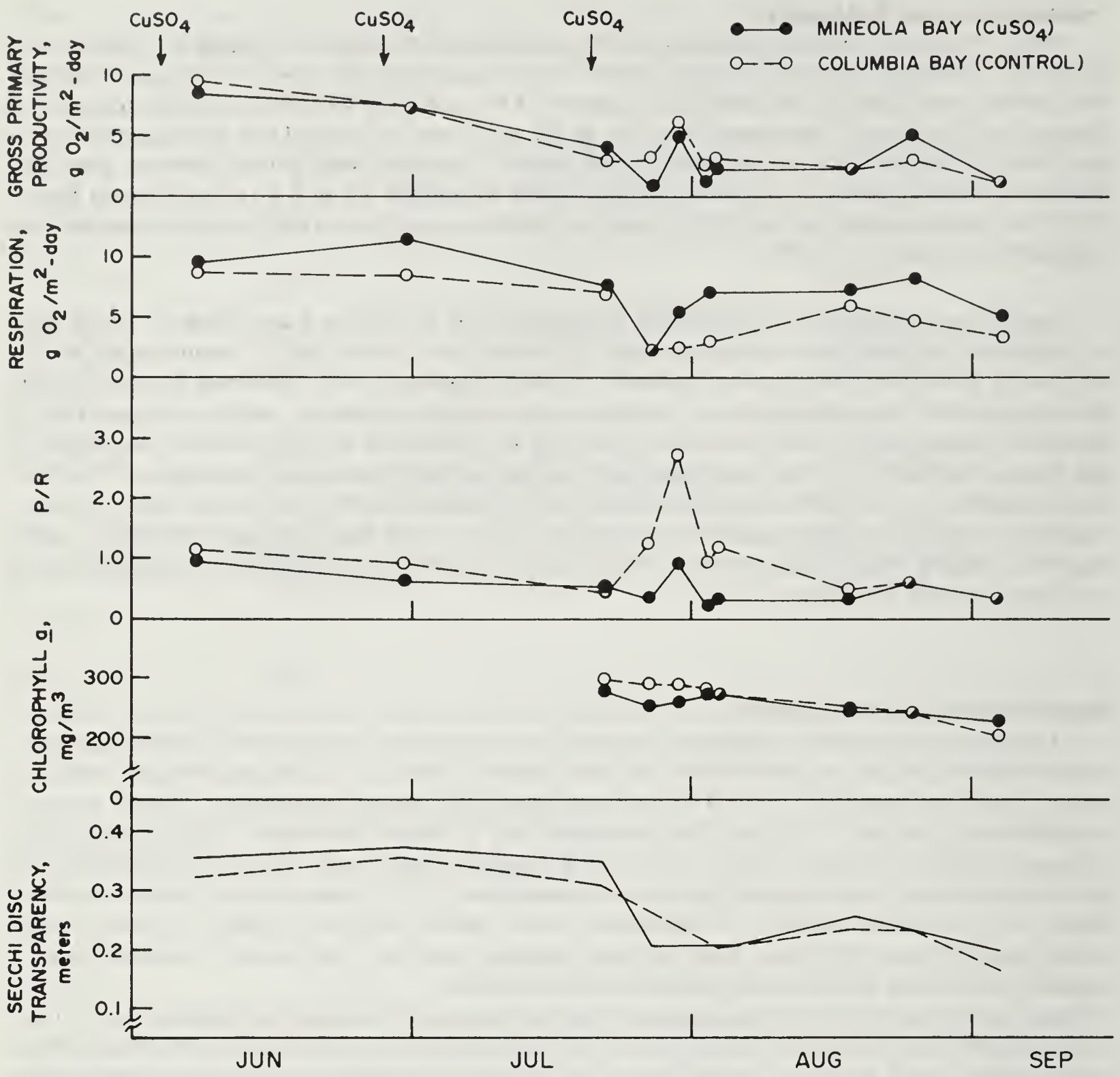

Figure 3. Results of metabolism, chlorophyll *a* and Secchi disk measurements for treated and control bays of Fox Lake during copper sulfate application.

Table 3. Comparison of Aquatic Metabolism of Lentic Systems Measured with Diel Oxygen Method

Reference	Study Site	g O_2/m^2-day	
		P	R
Welch (1968)	Lago Pond, Ga. (annual ave.)	5.3	7.6
Manny and Hall (1969)	Lake Michigan	23.7	26.4
Eley (1970)	Keystone Reservoir, Okla.	11.3-49.1	11.0-54.1
Nixon *et al.* (1976)	Narragansett Bay, R.I.(summer)	2.3-8.1	1.2-7.0
McKellar (1977)	Florida Estuary	5.3-5.6	2.6-2.9
Kaltenborn (1978)	Fox Chain of Lakes, Illinois		
	Bluff Lake (n = 7)	2.2-17.6	1.4-18.5
	Petite Lake (n = 7)	1.7.-11.1	1.9-11.8
This study	Fox Chain of Lakes, Illinois		
	Mineola Bay (n = 10)	0.6-8.6	2.3-11.5
	Columbia Bay (n = 10)	1.0-9.6	2.4-8.9

CONCLUSIONS

The following conclusions have been elucidated by this study on the Fox Chain of Lakes.

1. Copper sulfate, used as an algacide treatment in the Fox Chain of Lakes, has no apparent effect on aquatic primary productivity and no long term effect on phytoplankton biomass in the Fox Chain of Lakes.

2. Euphotic zone respiration was higher with copper sulfate treatment due to decomposition of dead algal cells. A noticeable scum of dead algae did appear after one of the treatments on the Fox Chain of Lakes, creating anesthetic problems as well.

3. Slight decreases in both dawn and dusk dissolved oxygen can be expected with the application of copper sulfate to the Fox Chain of Lakes. No dramatic dissolved oxygen depletions, however, can be expected due to the treatment.

4. Recovery of ecosystem function from the algacide stress in the Fox Chain of Lakes is rapid and almost complete within several weeks.

5. Overall aquatic primary productivity in the Fox Chain of Lakes, while extremely high on volumetric basis, is lower than some comparable ecosystems on an areal basis. It may be limited by shallow depths and highly turbid waters in the Fox Chain of Lakes.

6. Significant diurnal changes in dissolved oxygen occur during the summer and this should be considered when reporting dissolved oxygen for these lakes.

7. The Fox Chain of Lakes has bays and lakes with many different morphological and circulation characteristics and care should be taken in choosing the proper sites for experiments and controls.

ACKNOWLEDGEMENTS

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Food Habits of Larval Smallmouth Bass (*Micropterus dolomieui Lacepede*) in the Middle Fork Vermilion River, Vermilion County, Illinois.

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ABSTRACT

The food habits of 182 smallmouth bass larvae (*Micropterus dolomieui* Lacepede) collected from the Middle Fork Vermilion River on 14 June 1978 were investigated. The gut of each 8-23.5mm SL larva was filled to capacity with one or more of the following groups of food items; Copepoda, Cladocera, Chironomidae, Ephemeroptera, and other larval fishes. Statistical analyses of the percentage frequency of occurrence of those food items demonstrated a significantly greater ($P < 0.001$) use of zooplankters as a food source by larvae 8 to 14 mm SL, while bass larvae 14 to 20 mm SL fed significantly ($P < 0.001$) more often on aquatic insects. Smallmouth bass larvae 20 to 23.5 mm SL fed exclusively on aquatic insects and other larval fishes. The data suggest that as the bass larvae increase in length there is a concomitant increase in the size of their preferred food items resulting in a discrete partitioning of exploitable food resources. The importance of these data to year-class survival and recruitment is discussed.

INTRODUCTION

Numerous phenomena including density-independent factors such as floods, drought, extreme temperature changes, and pollution; and density-dependent factors such as predation, disease, and competition for a limiting food resource are believed to limit the survival of larval fishes through their "critical period." The critcal period is defined as that time during which year-class strength is established (Hjort 1926). During that time, starvation and starvation enhanced mortalities are particularly important density-dependent factors in determining the resulting year-class strength (Hjort 1926, Kramer and Smith 1962, May 1974, Hunter 1976, and Mortensen 1977).

Fry and Watt (1957) demonstrated that initial year-class strength of smallmouth bass was directly related to temperature from July through October of the first year of life. Forney (1972) was able to correlate only June temperatures and smallmouth bass year-class strength. Pfleiger (1966) noted a marked reduction in the abundance of smallmouth bass fry within the first few days after they left the nest in Little Saline Creek, Missouri. He suggested that inter- as well as intraspecific competition for food could have caused the reduction.

Extensive collections of adult and juvenile fishes from the Middle Fork Vermilion River during fall 1978 revealed an unusally large number of juvenile smallmouth bass which, we believe, reflected low critical period mortality among the larvae spawned that spring. Discussions with other fisheries biologists in Kentucky, Indiana, and Illinois revealed similar reproductive success in other smallmouth bass streams.

This study of food habits of larval smallmouth bass collected on 14 June 1978 was initiated in an effort to explain the apparent early recruitment success of this species in a small midwestern stream.

MATERIALS AND METHODS

The Middle Fork Vermilion River is a second order stream with a total length of approximately 103 km and a stream gradient in the study area of 1.25 m/km. Smallmouth bass larvae were collected in Vermilion County, Illinois, 40°11'10''N and 87°44'O''W. At a stream discharge of approximately 1 m^3/sec the average pool depth and width in the study area were 46 cm and 22m, respectively. In particularly wide stream pools (>28 m) the dominant substrate was limestone bedrock. Riffles averaged 16 cm in depth and 18 m in width. Dominant riffle substrate ranged from boulders to coarse gravel.

Water willow, *Justicia americana* (L.) Vahl., occurred in dense stands along pool margins and occasionally in shallow riffle areas. Although pool and riffle habitats occurred in a typically alternating pattern, the pools occupied approximately 75% of the available stream bed within the study section.

Icthyoplankton sampling in the Middle Fork Vermilion River revealed a smallmouth bass spawning period from late May through early June 1978. During that period, water temperatures increased steadily from 19°C to 25°C while stream discharge steadily decreased from 10.5 to 2.4 m^3/sec and dissolved oxygen levels were near or above saturation.

Larval smallmouth bass were collected from emergent beds of water willow along the pool margins of the river between 1300 and 1500 hrs on 14 June 1978 using a 900-μ-mesh D-frame dip net. Upon collection, the larvae were immediately preserved in 10% buffered formalin. This species is easily distinguished from other larval fishes by the heavy pigmentation which covers the entire body (Fig. 1). Early developmental descriptions of smallmouth bass larvae can be found in Meyer (1970) and Lippson and Moran (1974).

In the laboratory the standard length (SL) and maxilla length of each larva was measured to the nearest 0.1 mm using a dissecting microscope with a calibrated occular micrometer. Larvae were separated into 2-mm SL size classes for analysis of food habits.

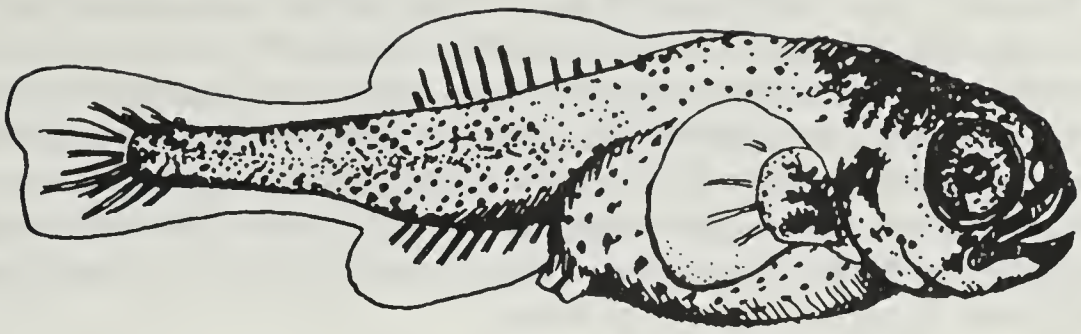
The entire digestive tract was removed from each larva and the stomach was separated from the intestine. Contents of both the stomach and intestine were removed and identified. The degree of fullness of each digestive tract was estimated using the method described by Marak (1974).

RESULTS

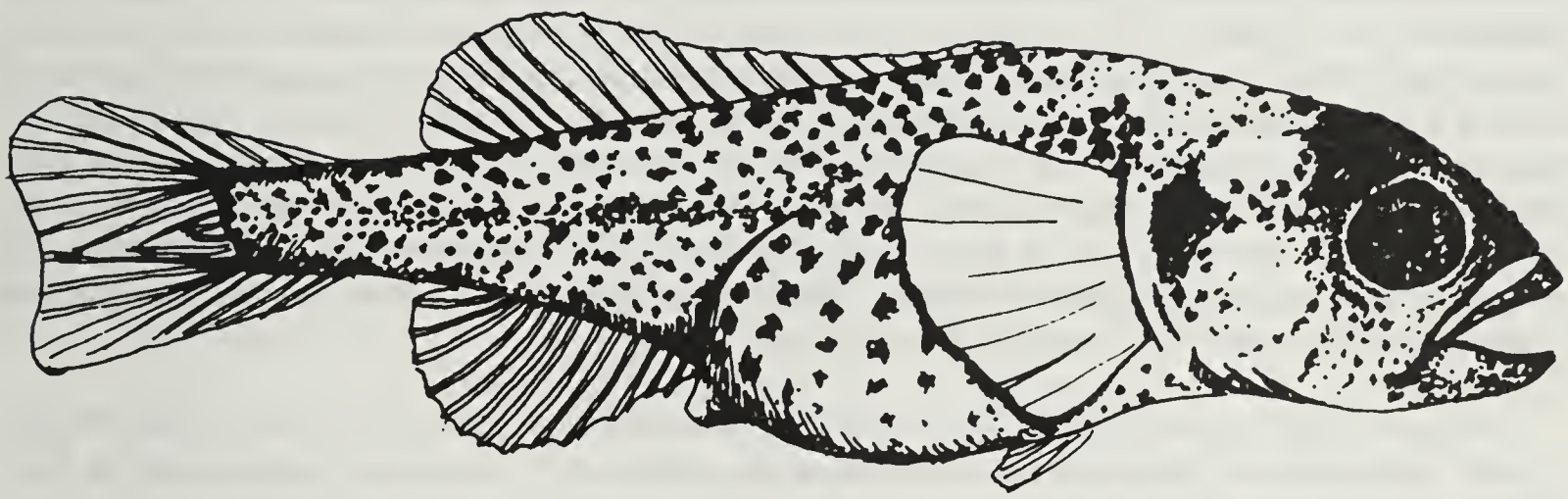
The major groups of food items encountered in the digestive tracts of the 182 larval bass measuring from 8.0 to 23.5 mm SL were zooplankton, insects, and fish larvae. The zooplankton consisted primarily of cyclopoid copepods, predominatly *Cyclops* sp., and an occasional cladoceran (*Daphnia* sp. and *Leptodora* sp.). The insects encountered were dipteran larvae and pupae, primarily of the family Chironomidae, and baetid and heptageniid mayflies. Fishes consumed by the smallmouth bass postlarvae were postlarval redhorse (*Moxostoma* spp.) and an occasional cyprinid larva.

Table 1 shows the percent frequency of occurrence of the major groups of food items encountered in each size class of smallmouth bass examined. Percent frequency of occurrence of zooplankton decreased as larval size increased, and no larvae greater than 18 mm SL contained zooplankters. The number of zooplankters/gut ranged from 1 to 79 ($\bar{X}$=27).

The percent frequency of occurrence of chironimid larvae and pupae increased steadily as larval size increased with a maximum number of pupae and larvae/gut of 5 and 17, respectively.



8.4 mm SL



11.9 mm SL

Figure 1. Prolarva (8.4 mm SL) and postlarva (11.9 mm SL) of the smallmouth bass (*Micropterus dolomieui*) from Middle Fork Vermilion River, Vermilion County, Illinois.

The greatest percent frequency of occurrence of mayflies was recorded in the 14-16 mm SL size class (62.5%). Mayflies were not utilized as a food source by postlarval smallmouth bass less than 14.7 mm SL.

Larval fishes were not consumed by smallmouth bass less than 20 mm SL, but occurred in 80% and 71.4% of the 20-22 mm SL and 22-24 mm SL size classes, respectively. Only one of the bass larvae (23.0 mm SL) examined had consumed more than one larval fish and that specimen had consumed two *Moxostoma* spp. larvae.

Table 2 presents a statistical comparison of percent frequency of occurrence of zooplankton and insects in 8-14 mm SL and 14-20 mm SL size ranges. Comparisons were made using the test for equality of two percentages (Sokal and Rohlf 1969). Results of the statistical test indicate that zooplankters were found significantly ($P < 0.001$) more often in the digestive tracts of bass larvae in the 8-14 mm SL size range while insects became the most frequently encountered food item ($P < 0.001$) in postlarvae measuring 14-20 mm SL. This partitioning of food resources probably corresponds to increasing mouth size as reflected by maxillary length. The mean maxillary length of smallmouth bass in the 8-14 mm SL size range was 1.7 mm while the average maxillary length of larvae in the 14-20 mm SL size range was 2.3 mm.

All smallmouth bass larvae examined had full or partially filled guts. Each larva contained an unusually large volume of food with some guts being so filled that the stomach walls were greatly distended. Intestines usually contained unidentifiable organic material, chironomid head capsules and, occasionally, one or more completely undigested chironomid larvae.

DISCUSSION

In similar studies, zooplankters were also found to be the primary food items consumed by smallmouth bass larvae once endogenous food reserved were exhausted (Clady 1974, Emig 1966, Hubbs and Baily 1938, Langlois 1936, and Wickliff 1920). Smallmouth bass larvae in the Middle Fork did not initiate feeding while yolk reserves were still available. Wickliff inspected the stomachs of 313 Lake Erie smallmouth bass between 8.5 and 65 mm. He noted that the food cycle was almost exclusively copepods and cladocerans to 15 mm; then from 16 to 45 mm mixed with mayfly nymphs midge larvae and pupae, fish and adult insects. Cladocerans and copepods were also important in the diet of 8-15 mm smallmouth bass from the Middle Fork but dipteran larvae and pupae were equally important. Pflieger (1966) found copepods, rotifers, and dipterous larvae in stomachs of smallmouth bass less than 10 mm.

Lachner (1950) first reported fish in the diet of smallmouth bass at 40 mm, while Pflieger (1966) indicated that fish were the most important food item in the diet of larvae over 15 mm. Pflieger reported piscivory in a single smallmouth bass larvae 11.8 mm SL. Fish were found in 1.3% of the guts of Lake Erie larval smallmouth bass 8.5-15 mm (Wickliff 1920). Emig (1966) found that fish became an important dietary item in smallmouth bass 1-2 inches. Fish were not found in the guts of smallmouth bass postlarvae from the Middle Fork less than 20 mm SL.

Mortensen (1977) suggested that an important factor regulating trout populations in streams is the availability of suitable areas for fry rearing. It seems reasonable to suggest that available rearing area may be an important density-dependent factor in determining year-class strength in smallmouth bass as well. In the Middle Fork Vermilion River, beds of emergent water willow apparently served as rearing areas offering both protection for smallmouth bass larvae and isolated stagnant water areas for the production and concentration of zooplankton (Hynes 1970). Larimore and Duever (1968) noted that a period of 3-4 weeks is required from egg deposition until smallmouth bass fry are able to withstand relatively severe environmental changes. Those 3-4 week old bass fry would typically exceed 25 mm TL.

Size of smallmouth bass prey is limited by their small mouth size and incomplete fin ray development at the time feeding is initiated (approximately 7-8 mm SL). Adequate population densities of zooplankters are undoubtably necessary for survival beyond the larval stage. In our study copepods were the numerically dominant food item in smallmouth bass less than 16 mm SL. The shift from zooplankton to insects (Ephemeroptera and Diptera) occurred following an increase in mouth size, as reflected by maxillary length, and the development of a full complement of all fin rays which greatly facilitated swimming ability and, presumably, food capture success.

Table 1. Frequency of occurrence of food items in the guts of larval smallmouth bass collected on 14 June 1978 from Middle Fork Vermilion River, Vermilion County, Illinois.

Standard length (mm)	Number Examined	Food Item (%)					
		Copepoda	Cladocera	Diptera (pupae)	Chironomidae (larvae)	Ephemeroptera	Larval Fishes
8-10	29	100.0	10.3		13.8		
10-12	24	83.3		16.7	41.7		
12-14	24	83.3	16.7	50.0	66.7		
14-16	24	50.0		50.0	87.5	62.5	
16-18	20	45.0		55.0	85.0	35.0	
18-20	20			80.0	100.0	60.0	
20-22	20			100.0	100.0	20.0	80.0
22-24	21			85.7	85.7	57.1	71.4

Table 2. Statistical comparison of percent frequency of occurrence (%) of zooplankton and insects in the guts of smallmouth bass larvae collected from the Middle Fork Vermilion River, 14 June 1978.

SL (mm)	n	Zooplankton (%)	Insects (%)	Significance level
8-14 mm	77	94.8	54.5	0.001
14-20 mm	64	20.3	100	0.001

Zooplankters were not consumed by larvae greater than 18 mm SL and it seems possible that they became an inefficient food source for the larger smallmouth bass larvae (Clark and Pearson 1979).

The addition of larval fishes to the diet of smallmouth bass greater than 20 mm SL was, similarly, reflected by increased maxillary length with a mean maxillary length of 3.5 mm for smallmouth bass between 20 and 24 mm SL. This study also suggests the possibility that smallmouth bass predation may be an important density-dependent mortality factor in regulating populations of redhorse and other fishes in the Middle Fork Vermilion River. It is interesting to note, however, that cannibalism has not been observed among smallmouth bass larvae (Webster 1954).

In 1978 no single factor or combination of factors had severely limited recruitment of smallmouth bass. We believe that there were two major reasons for the initial success of the 1978 year-class. First, many density-independent mortality factors were minimized due to the stability of the physical characteristics of the stream during spawning and early larval development. There were no sudden or drastic physical changes in stream characteristics during these periods. Secondly, our data indicate that starvation, an important density-dependent mortality factor, apparently did not limit population size of the smallmouth bass larvae. Many authors have reported that in a population of fish larvae a significant number have empty digestive tracts (Clark and Pearson 1979, Spykerman 1974 and Marak 1974), a phenomenon which was not evident in our study population. The amount of food consumed by smallmouth bass larvae in the Middle Fork Vermilion River on 14 June 1978 was limited only by the gut capacity. This apparently unusual availability of food for the smallmouth bass larvae coupled with a stable physical habitat seems at least partially responsible for the establishment of a strong year-class.

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A Survey of Grey Foxes (UROCYON CINEREOARGENTEUS) for ECHINOCOCCUS MULTILOCULARIS in Southern Illinois

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ABSTRACT

Six hundred seven *Urocyon cinereoargenteus* collected in Union, Williamson, Johnson, and Jackson counties, southern Illinois between June 1955 and October 1963 were examined for *Echinococcus multilocularis.* None were found infected with this cestode.

INTRODUCTION

The report of Rausch (1956) of *Echinococcus multilocularis* Leuckart, 1863, in the arctic fox, *Alopex lagopus* L., and the red fox, *Vulpes vulpes* L., on the mainland of Alaska constitutes the first published record of the etilogical agent of alveolar hydatid disease on the North American continent. Rausch (1956) predicted the establishment of this cestode in southern Canada and the contiguous United States, pointing out that sylvatic infection may be expected to occur whenever the predator-prey relationships existing between foxes and microtine rodents favor completion of the life cycle.

The first report of *E. multilocularis* on the Canadian mainland occurred 6 years later when Choquett *et al.* (1962) reported this species in *A. lagopus* from Eskimo Point on the western shore of Hudson Bay, Northwest Territories. Subsequent reports of *E. multilocularis* in carnivores and rodents from Canada have been numerous. Hnatiuk (1966) found the multilocular hydated stage of *E. multilocularis* in a meadow vole, *Microtus pennsylvanicus* Ord., near Saskatoon, Saskatchewan and in 1969 found the adult stage of *V. vulpes* in Saskatchewan. *Leiby et al.* (1969) found deer mice, *Peromyscus maniculatus* (Wagner) near Stony Mountain and Argyle, northwest of Winnipeg to be infected with the larval stage of *E. multilocularis.* Lee (1969) also reported this cestode in *P. maniculatus,* 10 miles north of this area at Gunton. Baron (1970) reported this tapeworm in *V. vulpes* from southern Manitoba. Recently, Samuel *et al.* (1978) reported it in coyotes, *Canis latrans* Say, and *V. vulpes* from southeastern Manitoba.

The first report of *E. multilocularis* in the contiguous United States was that of Leiby and Olsen (1964), who recorded this cestode from *V. vulpes* in North Dakota. The following year, Leiby (1965) found *M. pennsylvanicus* and *P. maniculatus* from North Dakota infected with the alveolar larval stage of this parasite. Leiby (1966) reported it from *V. vulpes, M. pennsylvanicus, P. maniculatus* and feral house mice, *Mus musculus* L. in North Dakota. The finding of this parasite in *P. maniculatus* and *V. vulpes* in Minnesota by Carney and Leiby (1968) constituted an eastern and southern extension of the known geographic range of this cestode in the contiguous United States. Leiby *et al.* (1970) reported adult cestodes in *V. vulpes* from Iowa, Minnesota, North Dakota, and South Dakota and in *C. latrans* in Iowa, Montana, North Dakota, and South Dakota. They also found the larval stage of this cestode in *P. maniculatus* from Iowa, Minnesota, Montana, North Dakota, and South Dakota, in *M. pennsylvanicus* from Iowa and North Dakota, and in *M. musculus* from North Dakota. Iowa, Montana, and South Dakota represented extension of this cestode's known geographic range in the contiguous United States.

Although several extensive studies on gastrointestinal parasites in wild canid populations have been conducted in North America, only a paucity of studies have been conducted on the gastrointestinal parasites of grey foxes. To our knowledge, natural infections of *E. multilocularis* have not been reported for *U. cinereoargenteus.* Because conditions for completion of the life cycle of *E. multilocularis* are equally favorable in southern Illinois and because Rausch (1958) has successfully infected *U. cinereoargenteus* experimentally with *E. multilocularis,* the data presented in this report deals with the examination of 607 *U. cinereoargenteus* collected over an 8-year period.

MATERIALS AND METHODS

Six hundred and seven (375 males and 232 females) grey foxes which included 11 animals in 1955, 13 in 1956, 24 in 1957, 4 in 1958, 21 in 1959, 103 in 1960, 290 in 1961, 72 in 1962, and 69 in 1963, were either shot or trapped in Union, Williamson, Johnson, and Jackson counties, southern Illinois, between June 1955, and October 1963.

The small intestine of each fox was opened, the lining scraped, and the contents and scrapings examined under a dissecting microscope for the presence of *Echinococcus multilocularis*. Other cestodes were fixed in alcohol-formalin-acetic acid (AFA) for future identification.

RESULTS AND DISCUSSION

Of the 607 grey foxes collected over an 8-year period from the four counties in southern Illinois, none were found infected with *E. multilocularis*. Examination of other carnivores from this area (unpublished data) has also not revealed the presence of this cestode. Studies are now in progress to examine *P. maniculatus* for the presence of the alveolar hydated larval stage, as late fall food habit studies of grey foxes from southern Illinois by Pils and Klimstra (1975) reveal a high percent frequency of occurrence of rodents (62%) in the diet of this carnivore.

As pointed out by Leiby *et al.* (1970), the widespread sylvatic occurrence of this cestode in the north central states is significant in zoonotic public health. While the presence of this tapeworm in grey foxes from southern Illinois has not been established by the present study, personnel who handle carcasses of foxes are warned to take precautions to avoid contamination with the eggs of this parasite.

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THE CONSTANCY AND DISTINCTNESS OF URBAN BIRD COMMUNITIES

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ABSTRACT

Temporal constancy and local distinctness are documented in 13 bird communities around Chicago. The bird community that was counted monthly followed a repeatable annual cycle. Annual variation among areas in the same year was greater than variation within areas between years. Disturbed urban areas were more constant between years and varied less among sites than forested areas.

INTRODUCTION

Community ecologists often assume that a community is at equilibrium in order to develop theories about competition, coexistence, and diversity. Tests of the equilibrium hypothesis require the discovery of regular patterns in the composition of communities. Annual repeatable cycles (temporal constancy) and repeatable differences between study areas (local distinctness) are two regular patterns that may support the equilibrium hypothesis.

The presence of regular patterns is not sufficient to demonstrate equilibria in urban bird communities. Communities in variable environments may never reach the equilibrium state (Connell, 1978). Temporal and local variation in the environment may lead to a steady state at levels below the equilibrial sizes determined by resources (Wiens, 1977). For example, the coexistence of plankton (Hutchinson, 1961) in a lake environment demonstrates nonequilibrial coexistence. In a like manner urban bird communites are open systems without clearly defined limits between communites. Birds may fly across habitat boundaries, or migrate to other areas. The seasonality of breeding and nonbreeding periods further complicates the study of temperate-zone birds (Fretwell, 1972).

Temporal constancy and local distinctness may distinguish urban bird communities in spite of the variable environment. This study tests (1) the constancy of community composition between years in a study area, and (2) differences in community composition between local sites, such that the assemblages of birds at two different sites may be regarded as distinct communities.

STUDY AREAS AND METHODS

Thirteen study areas were selected to cover a range of habitats from intense urban to forested suburb and forest, and from grassy cemetery with few trees to developed suburbs with few trees. Study areas are listed in Table 1, and detailed locations are listed in Guth (1980). Densities of large trees taller than 7 m were computed to give an indication of habitat type (Table 1). Each sampled area included more than 16 ha.

Birds were sampled by the segment method (Geis, 1974). Bird counts usually began within 30 minutes of sunrise. A sample coverage of all segments included four-minute counts of all birds seen or heard using each segment. I sampled 10 to 24 segments (91.4 m x 91.4 m) within each study

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area. The Evanston study area was sampled almost monthly over a 24-month period. Other areas were sampled during June of at least two consecutive years between 1974 and 1977. Bird densities per segment were computed for each month and study area, and 95% confidence intervals were computed using the standard error between segments.

Communities were compared using an index of bird species difference adapted from MacArthur (1972, p. 189):

$$\text{Bird species difference} = \frac{2}{1 + \dfrac{2 \Sigma p_i q_i}{\Sigma p_i^2 + \Sigma q_i^2}} - 1$$

where p_i and q_i are the relative abundances of the *i*th bird species in the study areas considered. This index is 0.0 for identical communities, and 1.0 for communities with no species in common. The most abundant species are given the greatest weight in this index. Bird species difference was compared between months in Evanston, and between years and areas in June for all study areas. A cluster analysis was used to ordinate bird species difference between areas. In the cluster analysis each study area was grouped with the area or cluster containing the area that had the least bird species difference from the study area. The N_2 index (Hill, 1973), where $D = 1/\Sigma p_i^2$, was used to describe species diversity. Linear correlation was used to analyze bird density and diversity, and nonparametric statistics were used to analyze bird species difference.

RESULTS

The Evanston bird community followed a regular annual cycle. The number of Evanston species was 4 to 7 each winter, and 6 to 9 in June. A surge of migrants appeared each April and May (up to 25 species seen), and each September and October (up to 15 species seen). Bird densities per segment for the monthly Evanston counts are listed in Guth (1980). Bird species diversity D in Evanston was correlated with bird species diversity twelve months earlier ($r = .63$, $p < .01$), but was not significantly correlated with bird species diversity found one month earlier ($r = .19$, $p > .40$). The median value of bird species difference for Evanston bird counts within the same month was .0048. The median difference for counts twelve months apart was .0043 (8 of 16 larger than within months, sign test, $p \cdot > .40$), but for counts one month apart, the median was .0093 (16 of 21 larger than within months, $p < .02$). Total density was less strongly correlated with densities one month earlier ($r = .43$, $p < .05$) and one year earlier ($r = .06$).

Annual variation within areas was lower than variation among areas for all study sites (Table 1, Figure 1). Between-areas June bird species difference exceeded the within-areas difference in 153 of 156 cases (sign test, $p < .01$). There was significant repeatability to the June bird count results in most areas (Guth, 1980). The largest bird species differences within areas (Busse Forest edge and Busse Forest mixed) may reflect the small number of birds observed in these two areas.

Residential areas were less variable in June than forest areas (Figure 1). Bird species difference within residential areas was less than .06 and was significantly smaller than difference within forest areas (Wilcoxon's two-sample test, $T = 10$, d.f. = 7, 4; $p < .01$). Four inner-city residential areas (North Central Chicago, Evanston, Skokie, and Wilmette) formed a very similar group of bird communities with little difference. Bird species difference between the four inner-city areas was less than .11 and was significantly smaller than difference between forest areas ($T = 21$, $p < 01$) or between inner-city and forest areas ($T = 21$, $p < .01$).

TABLE 1. Tree density and bird species difference within 13 study areas between years for June censuses.

Study areas	Number of years	Tree density per segment	Bird species difference within areas
Residential areas:			
Chicago Loop	2	0	.003
North Central Chicago	4	18.3	.008
South Evanston	4	28.8	.010
Skokie	4	24.8	.024
Wilmette	4	42.3	.043
Addison	3	12.2	.059
Lake Forest	4	53.4	.026
Cemeteries:			
Calvary Cemetery	3	7.0	.021
Rosehill Cemetery	2	29.7	.060
Forests:			
Busse Forest edge	3	164	.218
Harms Woods	2	87.8	.074
Busse Forest	3	235	.062
Busse Forest mixed	3	81.8	.346

DISCUSSION

Although urban communities represent an advanced state of human disturbance, simplification, and utilization (Curtis, 1956), there is remarkable constancy of community composition between years in these urban sites. Human disturbance of forests and grasslands has created unprecedented constancy in vegetation (Detwyler, 1971, p. 507). The bird species difference within sites between years suggests a similar several-fold increase in community constancy of urban sites compared to forest.

Regular sustained disturbance may contribute to very constant local communities. Human disturbances of the urban ecosystem are frequent and extensive (Falk, 1976). Studies of extensive forests now suggest that high diversity may be maintained by repeated disturbance (intermediate disturbance hypothesis of Connell, 1978). Turnover between years in small forest woodlots is well documented (Whitcomb *et at.,* 1976). If ''stable'' forest systems have internal fluctuation, urban systems may represent more constant local communities than forest systems. Although urban bird densities may greatly fluctuate, relative abundances of birds are constant between years and vary between neighborhoods (Guth, 1979).

Variation among forest sites is higher than among disturbed sites. Bird species difference among the four forest study areas is higher than among the four inner-city urban areas above, or between the two cemeteries (Figure 1). In tropical and temperate forests, beta diversity is high, and local forests vary greatly in community composition. Although total variation between disturbed sites is reduced, different sites are significantly different, because local constancy of disturbed sites is greater than that of forests. Reduced variation among disturbed sites may contribute to local constancy in these sites.

The dynamic stability of these urban systems is unresolved in spite of the observation of constancy. Extensive invasions of exotic birds in some metropolitan areas (Bull, 1973; Hardy, 1973; Owre, 1973) point to the invasibility of urban faunas. Whether competitive equilibria account for the predictable responses to environments requires additional investigation.

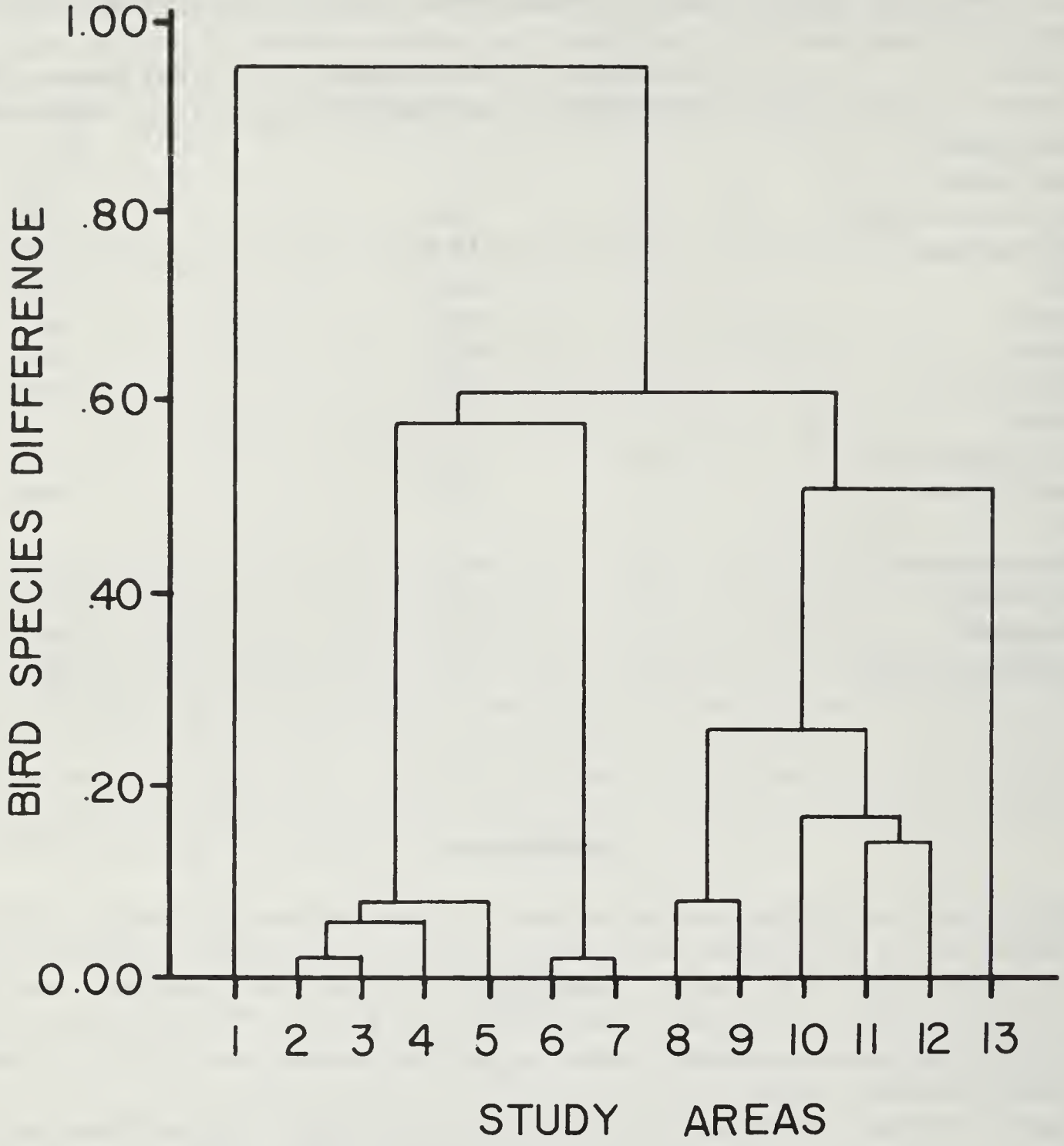

FIGURE 1. Cluster analysis of bird species differences between study areas. The closest areas or groups of areas are joined such that community distinctness is illustrated. The study areas are (1) Chicago Loop, (2) North Central Chicago, (3) South Evanston, (4) Skokie, (5) Wilmette, (6) Calvary Cemetery, (7) Rosehill Cemetery, (8) Addison, (9) Lake Forest, (10) Harms Woods, (11) Busse Forest edge. (12) Busse Forest mature, and (13) Busse Forest mixed. Note the closeness of urban areas 2 to 5 compared to forest areas 10 to 13.

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WINTER FOOD HABITS OF COYOTES IN SOUTHEASTERN ILLINOIS[1]

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ABSTRACT

Food habits of coyotes *(canis latrans)* in southeastern Illinois were investigated between November 1977 and February 1978. Cottontail *(Sylvilagus floridanus),* livestock, and rodents accounted for 49.7, 13.9 and 12.6%, respectively, by volume of the winter diet based on analyses of contents of 89 stomachs. Other important prey species were white-tailed deer (*Odocoileus virginianus)*, raccoon (*Procyon lotor*), and poultry.

INTRODUCTION

The coyote has traditionally been the focal point of much controversy. Many of the conflicting views arose from its food habits, especially in areas of livestock production (Young and Jackson 1951). The coyote ordinarily preys on rabbits, mice, birds, and insects with domestic livestock comprising only a small percentage of its diet (Sperry 1941, Murie 1945, Korschgen 1957, and Mathwig 1972). Overall, the coyote is best described as an opportunistic predator since it consumes what is most available and easiest to catch.

The coyote food-habit controversy appeared far removed from Illinois until recently. Livestock and poultry production has long been an important industry in Illinois, but prior to 1972, few coyotes were reported and pelt harvests were low (Mohr 1943, Hoffmeister and Mohr 1957, and Ellis, unpublished data).

After 1972, however, coyote populations apparently increased. Pelt harvests climbed from about 400 in 1973-74 to 9,891 in 1978-79 (Hubert 1979). As coyote populations increased, reports of livestock depredation by coyotes increased (Hubert, unpublished data) and upland wildlife populations decreased—specifically cottontail and ring-necked pheasant (*Phasianus colchicus*) (Preno and Labisky 1971) and bobwhite (*Colinus virginianus*) (Ellis, unpublished data).

Currently in Illinois, coyote populations are increasing, livestock is abundant, and certain recognized prey species are scarce. Before this study no coyote food-habits data were available from Illinois. The objective of this study was to determine the quality and quantity of foods eaten in winter by a sample of coyotes from southeastern Illinois.

MATERIALS AND METHODS

Coyote carcasses were collected from fur buyers near Noble, Richland County, and Hord, Clay County, in southeastern Illinois between 29 November 1977 and 28 February 1978. Method of harvest for each animal (shot, trapped, or road-killed) was ascertained by external examination. All

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coyotes were caught within 100 km (62 mi) of the furhouse where they were collected, but the exact capture locations were usually unknown. About 16% of this area is forest (Essex and Gansner 1965) and approximately 60% is fields of corn, soybeans, wheat, and hay (Illinois Cooperative Crop Reporting Service 1979). Schwegmann (1973) included most of the area in the Southern Till Plain and Wabash Border natural divisions and presented details of the vegetative, faunistic, and topographic features.

Stomachs were removed from carcasses as soon as possible after death, placed in individual plastic freezer bags, and stored at -18 C until examination. Each sample was thawed and processed following the standard procedures outlined by Martin (1949) and Korschgen (1969). Only stomachs from shot animals were used for food-habits analysis, because trapped animals may contain a preponderance of bait which can bias results (Murie 1935). Food items were blotted with paper towels to remove excess moisture and the volume of each measured in a graduated cylinder to the nearest ml by water displacement. Volumes less than 1 ml were reported as trace quantitites. Data were analyzed relative to percentage occurrence and aggregate volume (Martin et al. 1946).

RESULTS

A total of 140 coyote stomachs was collected during the study. Of these, 15 were obtained in November 1977, 37 in December 1977, 41 in January 1978, and 47 in February 1978. Thirty-one stomachs (22%) were empty and an additional 20 (14%) were discarded as unusable (contaminated by gunshot wounds or from trapped animals). The remaining 89 stomachs provided data about the principal winter foods of coyotes in southeastern Illinois (Table 1).

Mammals as a group occurred in 98% of the stomachs and occupied 87.7% of the aggregate volume. The second most frequently utilized food group was birds, which occurred in 24.7% of the stomachs and occupied 3.4% of the aggregate volume. Undetermined animal matter occurred in 20.2% of the stomachs and occupied 8.0% of the aggregate volume. Plant foods occurred in 92.6% of the total stomachs yet occupied only 1.2% of the aggregate volume (Table 1).

Cottontail, the most utilized prey during the study period, occurred in more than half of the stomachs (51.6%) and occupied 49.7% of the total volume (Table 1).

Mice as a group proved to be the second most frequent food source (Table 1). Four species were identified in the stomach contents: meadow vole (*Microtus pennsylvanicus*), deer mouse (*Peromyscus maniculatus*), white-footed mouse (*P. leucopus*), and house mouse (*Mus musculus*). The white-footed mouse was the most important rodent. This species occurred in 15.7% of the stomachs and occupied 5.4% of the total volume.

Livestock was the third most frequently consumed food group. This category consisted primarily of pig (22.4% occurrence and 13.9% aggregate volume). Sheep and poultry were less frequently eaten and comprised less volume (Table 1).

A number of other mammals were also consumed. Among these, white-tailed deer was the most common, occurring in 6.7% of the stomachs and occupying the greatest aggregate volume, 7.0% (Table 1). Other mammals eaten included raccoon, striped skunk (*Mephitis mephitis*), and woodchuck (*Marmota monax*).

Among the avian species consumed, bobwhite was the most frequent (11.2% occurrence) and occupied a trace amount of the total volume. Poultry occurred less frequently than bobwhite (10.1% occurrence) but occupied a greater portion of the total volume (2.9% aggregate volume) (Table 1).

As stated above, plant foods occurred in 92.6% of the stomachs examined. Grasses (Graminae spp.), the primary plant food identified, were present in 71.9% of the samples and accounted for .5% of the aggregate volume (Table 1). Other plants, most notably corn and persimmon (*Diospyros virginiana),* were also consumed.

DISCUSSION

Foods eaten by coyotes are a matter of concern to husbandrymen, farmers, and hunters because of real or imagined effects of coyotes on livestock, farm produce, and game species. This concern seems to be growing in Illinois as the coyote population grows. By understanding this mammal's food habits, we can better assess its economic impact.

A number of studies have shown rabbit to be the major food item for coyotes (Sperry 1941, Korschgen 1957, Gier 1968, and Clark 1972). Seasonal data indicate that rabbits are most important in the coyote diet during winter, the least important during summer (Korschgen 1957, Boggess 1975, and Niebauer and Rongstad 1977). The degree to which rabbits are utilized during winter varies with the weather (Korschgen 1957, and Niebauer and Rongstad 1977). Heavy snows seems to increase utilization of rabbit by coyotes, whereas in mild winters with little snow, rabbits are less concentrated in heavy cover and a lower utilization by coyotes results. Our study further reinforced this idea as the 1977-78 winter was one with abnormally low temperatures and heavy snows (Hubert 1979).

The importance of mice in the coyote's diet is well documented (Sperry 1941, Murie 1945, Korschgen 1957, and Clark 1972). Eadie (1954) found that each small rodent in a pasture or hay field eats approximately its own weight in grass daily and consumes as much as 25 pounds of grass annually. These rodents also damage shrubs, trees, and stored grains. Gier (1968) reported that an average coyote in Kansas consumes 1,000 mice per year, saving the farmer $20.00 per year. Coyotes undoubtedly save Illinois farmers money in much the same fashion.

The area of greatest controversy stems from the coyote feeding on domestic livestock and poultry. Several researchers have found that cattle and poultry comprise a substantial portion of the coyote's diet (Korschgen 1957, Boggess 1975, and Boggess et al. 1978). Our study indicated that pig was the most important livestock component with sheep, and poultry comprising much smaller percentages. Therefore, it seems the domestic animal most frequently consumed by coyotes depends on availability.

The problems of assessing the utilization of livestock by coyotes are many. Carrion probably constitutes a major source of the livestock and poultry in coyote stomachs, but it is impossible to identify in all but the freshest stomachs (Korschgen 1957, and Mathwig 1972). Poor animal-husbandry practices further compound food-habits evaluation. Practices such as discarding dead farm animals in remote areas may skew data toward apparent increased livestock predation. Poor animmal-husbandry can also lead to habituation. In this situation the coyotes develop a taste for livestock or poultry, which may lead to actual predation as opposed to scavenging (Fichter et al. 1955, and Gier 1968).

The problem of livestock predation by coyotes is real, but recent studies suggest the pattern of predation reflects a Poisson distribution, with most ranchers experiencing few losses and a small number of ranchers receiving varying degrees of intense damage (Wagner 1975, and Sterner and Shumake 1978). Operators experiencing high losses should review their production techniques in an attemp to reduce losses.

Livestock predation is not the only area of concern regarding the coyote. Many hunters contend that coyotes reduce upland game species. McKean (1948) concluded, after examination of 595 carnivore stomachs in North Dakota, that no predator was more than moderately detrimental to game animals in winter. Studies conducted in California illustrate essentially the same point (Bond 1939). Leach and Frazier (1953) concluded that valley quail (*Callipepla californica*) are a minor prey species for coyotes and that control of coyotes is of doubtful value even in areas of high quail concentrations. Our results further reinforce this idea. Although bobwhite was the bird most frequently eaten, it was never found in large amounts.

Plants, such as persimmons, are utilized extensively by coyotes (Korschgen 1957, and Gipson 1974). The persimmon had the highest annual percentage occurrence of coyote foods from Arkansas; it was also the most common autumn food item (Gipson 1974). Other plants, such as

apples, pears, and watermelons, represent additional food sources for coyotes. However, we feel that some plants, such as persimmons, are eaten intentionally, whereas other plants, such as grasses, are eaten unintentionally or are contained in prey species stomachs and do not constitute a major food source.

The present study failed to reveal any new and astonishing concepts about coyote feeding habits. However, it did emphasize the fact that under certain conditions Illinois coyotes may utilize livestock, in this case swine, as an important food source. As the coyote population increases and their range extends, the opportunity for interactions between coyotes and livestock will increase. Therefore, to better assess this relationship, additional coyote food-habits research during other seasons and in other sections of the state is warranted.

ACKNOWLEDGEMENTS

The authors wish to thank David F. Fender and Albert H. Hasler for providing coyote carcasses. Richard R. Graber and Jean W. Graber, Illinois Natural History Survey, and Donald F. Hoffmeister, University of Illinois, provided assistance in the identification of food items. Glen C. Sanderson, Illinois Natural History Survey, provided assistance in study design, identification of food items, and editorial comments. Eva Steger, Illinois Natural History Survey, edited the manuscript.

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Table 1. Winter foods of coyotes in southeastern Illinois as determined by analysis of 89 stomachs collected from 29 November 1977 through 28 February 1978.

Food Item	Frequency of occurrence (%)	Aggregate volume (%)
MAMMALS	98.0	87.7
Rabbits		
Cottontail	51.6	49.7
Deer		
White-tailed deer	6.7	7.0
Rodents		
Woodchuck	1.1	1.5
Meadow mouse	3.3	tr.[a]
White-footed mouse	15.7	5.4
Deer mouse	8.9	1.8
House mouse	7.8	2.2
Undetermined mouse	17.8	1.7
Livestock		
Pig	22.4	13.9
Sheep	1.2	tr.
Other mammals		
Racoon	4.4	3.3
Striped skunk	5.6	0.8
BIRDS	24.7	3.4
Poultry	10.1	2.9
Game birds		
Bobwhite	11.2	tr.
Non game birds		
Redwinged blackbird *(Agelaius phoniceus)*	1.0	tr.
Bluejay (*Cyanocitta cristata)*	1.0	tr.
Eastern Meadowlark *(Sturnella magna)*	2.2	tr.
Swamp sparrow *(Melospiza georgiana)*	1.0	tr.
Tufted titmouse *(Parus bicolor)*	1.0	tr.
INVERTEBRATES	2.2	tr.
Crustaceans		
Crayfish *(Cambaridae* spp.)	1.0	tr.
Insects		
Grasshopper (Acrididae sp.)	1.0	tr.
UNDETERMINED ANIMAL MATTER	20.2	8.0
PLANT FOODS	92.6	1.2
Persimmon *(Diospyros virginiana)*	5.6	tr.
Grass *(Graminae spp.)*	71.9	0.5
Corn	11.2	tr.
Potato	1.0	tr.
Soybean	1.0	tr.
Goosefoot *(Chenopodium hybridum)*	1.0	tr.
MISCELLANEOUS	7.8	tr.
Paper	5.6	tr.
Leather	1.0	tr.
Rubber	2.2	tr.
Plastic	1.0	tr.

[a]tr. = trace (less than 0.5%)

The First Record in Southern Illinois of *Celestrina ebenina* (Lepidoptera: Lycaenidae)

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ABSTRACT

The first record of *Celastrina ebenina* Clench in southern Illinois is reported.

The dusky blue, *Celastrina ebenina* Clench, based on scattered collection records, occurs from Pennsylvania and Maryland south to North Carolina, and west to Illinois, Missouri and Arkansas (Wagner and Mellichamp 1978). Specific localities along the western edge of its range include Elsah, Jersey Co., Illinois; Creve Coeur Lake, St. Louis Co., Missouri; and Hickory Flat Hollow, Washington Co., Arkansas (Wagner and Mellichamp 1878).

The dusky blue's range lies within that of goat's-beard, *Aruncus dioicus* (Walter), its only reported larval foodplant (Wagner and Mellichamp 1978). This plant is found locally in southern Illinois (Mohlenbrock and Voigt 1959), including in the La Rue-Pine Hills Ecological Area, Union Co. (Mohlenbrock and Voigt 1965).

During 1979, we collected 2 adult female specimens of *C. ebenina* in Pine Hills, one on 27 April and the other on 5 May; Pine Hills is ca. 100 miles south of Elsah, the site of the only other Illinois record. On each occasion, it was flying with *C. argiolus pseudargiolus* (Boisduval & Le Conte). We also found an adult male among unidentified material in the SIU-C collection, which was collected in Pine Hills on 14 April 1962 by E. J. Dobbs.

The three specimens are housed in the SIU Entomology Collection, Zoology Research Museum.

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NUCLEASE ACTIVITY IN ISOLATED TOMATO LEAF NUCLEI

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ABSTRACT

Two techniques for isolating tomato leaf nuclei are compared; one technique uses no detergent and the other uses an isolation medium containing 2% Triton X-100. The addition of Triton X-100 removed a film or membrane surrounding the isolated nuclei. Isolated nuclei with membranes had RNase and DNase activities with pH optima at 6.0 and 6.4. Isolated nuclei without membranes had only pH 6.4 activity. Both types of nuclear preparations destroyed their nucleoli upon incubation without exogenous substrate.

INTRODUCTION

Few studies of nuclei isolated from higher plants have been undertaken, compared to the extensive studies performed using isolated animal nuclei. Three major problems have made the isolation of plant nuclei particularly difficult: (1) mechanical rupture of the cell wall frequently deforms and damages the nucleus, (2) chloroplasts and amyloplasts have sedimentation constants in dilute aqueous solutions similar to nuclei, so that separations by centrifugation are often difficult, and (3) plant parts have highly active nucleases which may destroy the nucleic acids during isolation and result in nuclei having reduced biochemical activity. Various schemes have been used to overcome these isolation difficulties. Hamilton, et al. (1972) modified an earlier method of Kuehl (1964) by adding a cold diethyl ether treatment to facilitate release of nuclei from cells and a detergent to disperse contaminants during centrifugation. Increased yields of nuclei were obtained by D'Alessio and Trim (1968) when a pectinase from snail digestive juice was infiltrated into tissues at low temperature prior to grinding. Honda, et al. (1966) described an isolation medium containing sucrose as an osmoticum, Tris acetate as a buffer, Ficoll and bovine serum albumin as structural preservatives and mercaptoethanol as an anti-oxidant (reducing agent). Our study combines features of all these techniques; it uses the isolation medium of Honda, et al. (1966), modified to improve the partitioning effect of differential centrifugation and enzyme and diethyl ether treatments to increase the nuclear yield during tissue grinding. The nuclease activities of detergent-treated nuclei are compared with the nuclease activites of untreated nuclei to estimate the effectiveness of a detergent in removing nuclease activity.

Materials and Methods

Young tomato (*Lycopersicon esculentum* cv. Marglobe) plants were grown in soil under greenhouse conditions for 10 weeks and then kept in the dark for 24 to 48 hours to deplete their leaves of starch which might sediment with the isolated nuclei. Leaflets 3 cm. long or longer were removed from their rachis, surface-sterilized by immersion for 30 seconds in cold (0° to 4°C) 70% ethanol, followed by 2 minutes in 5% Chlorox and a rinse in sterile, demineralized water. Five gram portions were blotted, the midribs were removed, and the leaflet strips were immersed in diethyl ether for 30 seconds, followed by a wash in cold isolation medium. The isolation medium contained 0.05M Tris, 0.36M sucrose, .001M $MgCl_2$ and 10% Ficoll, adjusted to pH 7.5 with HCl.

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Next, the cell walls of the leaf strips were digested for 2 to 8 hours with 10 ml of a mixture of 20% cellulase (Calbiochem, LaJolla, Ca.) and 50% pectin methyl esterase prepared from ripe tomato fruits (Hobson, 1963), in cold isolation medium. The fully-infiltrated leaf strips were thoroughly minced in 10 ml of fresh isolation medium without cellulase or pectin methyl esterase using a razor blade. The minced brei was passed through 2 layers of fine mesh nylon cloth and the mincing and filtering procedure was repeated twice using fresh 10 ml portions of isolation medium. Finally, the remaining residue was placed in a nylon bag with 20 mg. of sterile acid-washed sand and pulverized in a sterilized, chilled mortar containing 10 ml of cold isolation medium; this final medium was filtered and all filtrates were combined. The combined filtrates were centrifuged at 20 g for 10 min. in a Sorvall RC-2B centrifuge using a SS-34 rotor. The supernatant fluid was removed and centrifuged at 30 g for 10 min. The pellets of the two centrifugations were washed by resuspending them in 10 ml of isolation medium and recentrifuging them; the wash solutions were discarded. A morphologically different preparation was obtained in some nuclear isolations by washing the pellets with 2% Triton X-100 in isolation medium, followed by a rinse using isolation medium without Triton X-100. Portions of each of these pellets were stained for DNA using the Feulgen Method (Humason, 1969), counterstained with Fast Green FCF and observed under the light microscope. Other portions were fixed in 3% glutaraldehyde, post-fixed with osmium tetroxide, embedded in Spurr's medium (Spurr, 1969), stained with uranyl acetate-lead citrate, and observed under the electron microscope.

Nuclease enzyme assays were performed on aliquots of the pellets resuspended in isolation medium and aliquots of the supernatant fraction from the 30 g centrifugation. The pH of the assay mixtures was maintained at 6.0, 6.2 or 6.4, using 0.4M phosphate buffer; there was no evidence of phosphate inhibition of nuclease activity. Yeast RNA (Miles Laboratories) and calf thymus DNA (Sigma Chemical Company) were used as substrates. Details of the assay have been described in an earlier paper (Dove, 1967). Tomato leaf nucleases were found in an earlier study to have pH optima of 6.0, 6.2 and 6.4 (Dove, unpublished). Activity is expressed in the units recommended by Wilson (1975).

Results and Discussion

Ficoll in the isolation medium increased the viscosity without increasing the osmotic pressure significantly. Consequently, nuclei were pelleted slowly and their structural integrity was largely preserved. Figure 1 shows two typical isolated nuclei with sharply defined boundaries and prominent nucleoli. Use of Triton X-100 modified their structure, making nuclear features appear less distinct under the light microscope. Nuclei observed under the electron microscope show membrane material in preparations not treated by Triton X-100 (Figure 3), while Triton X-100 treated nuclei lack membrane material, presumably because the detergent Triton X-100 extracts lipid from these preparations (Figure 4).

The nuclear isolation medium containing pectinase and cellulase showed some RNase, but no DNase activity; the data presented here have been corrected to show only nuclear RNase and DNase activities. The ability of nuclear preparations to degrade yeast RNA varied significantly as a function of pH (Table 1). The greatest RNase activity of detergent-treated nuclei occurred at pH 6.4, while untreated nuclei showed optimal activity at pH 6.0. The least activity occurred at an intermediate pH of 6.2, suggesting that two RNases were present and the RNase active at 6.0 was inactivated or extracted by the detergent. The RNase active at 6.4 was made more active in intact nuclei by detergent treatment; this activation did not occur when nuclear fragments were used (Table 2). Detergent-treated nuclear preparations slowly degrade calf-thymus DNA, with a DNase activity of .074 units ($o^2 = .002$, $n = 12$) at a pH of 6.4. When isolated nuclei were incubated for 24 hours without yeast RNA or calf-thymus DNA, they lost their nucleoli and most of their Feulgen-positive material.

These data indicate that a tightly-bound nuclease exists in tomato leaf nuclei which breaks down exogenous RNA and DNA; it also breaks down native RNA in the nucleolus and nuclear DNA (Feulgen-positive material). Treatment of isolated nuclei with Triton X-100 detergent removes some other nuclease, but makes the pH 6.4 enzyme more active and destroys membranes. The isolation procedure described here removes nuclei in good morphogical condition from tomato leaves when detergent is not used, but these nuclei must be used immediately before nucleic acid breakdown becomes extensive.

Table 1. Ribonuclease Activity of Detergent-treated and Non-detergent-treated Nuclear Preparations.

Isolation Procedure	Type of Nuclear Preparation	pH of Assay	Mean RNase Activities*
Detergent	Intact Nuclei with Membranes	6.0	0.048
Detergent	Intact Nuclei with Membranes	6.2	0.0125
Detergent	Intact Nuclei with Membranes	6.4	0.168
Non-detergent	Intact Nuclei without Membranes	6.0	0.127
Non-detergent	Intact Nuclei without Membranes	6.2	0.0098
Non-detergent	Intact Nuclei without Membranes	6.4	0.084

*RNase activities were significantly different at different pH values ($P < .99$, $n = 12$).

Table 2. Ribonuclease Activities of Detergent-treated and Non-detergent-treated Nuclear Preparations and Nuclear Fragments Assayed at pH 6.4

Isolation Procedure	Type of Nuclear Preparation	Mean RNase Activities*
Detergent	Intact Nuclei without Membranes	0.1782
Non-detergent	Intact Nuclei with Membranes	0.0986
Detergent	Nuclear Fragments without Membranes	0.0410
Non-detergent	Nuclear Fragments with Membranes	0.0850

*Detergent treatment increases the RNase activity of intact nuclear preparations and decreases the RNase activity of nuclear fragment preparations ($P < .99$ in each case; $n = 12$). The nuclear fragment preparation was the supernatant of the 30g centrifugation.

ACKNOWLEDGEMENT

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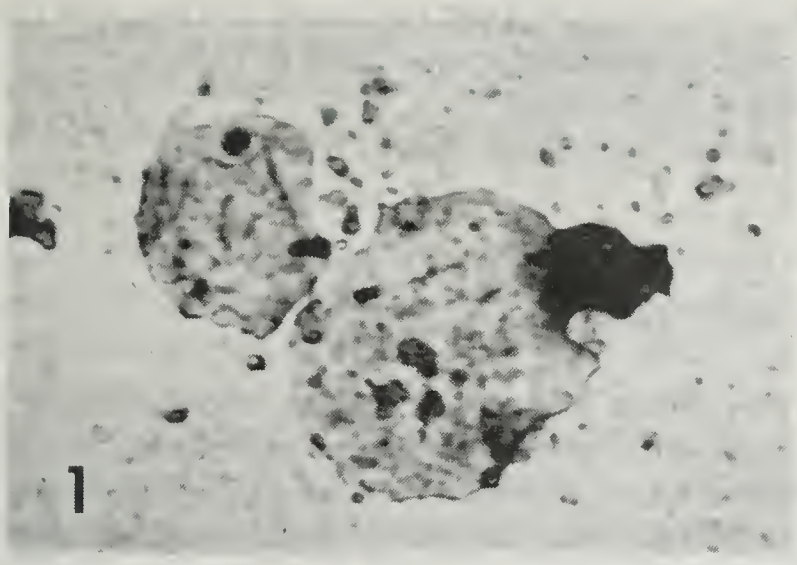

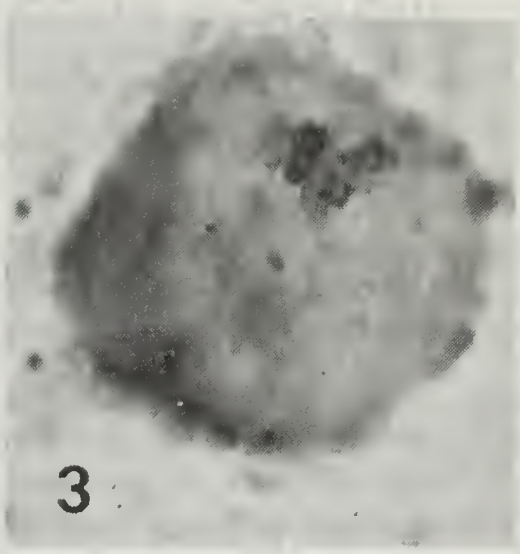

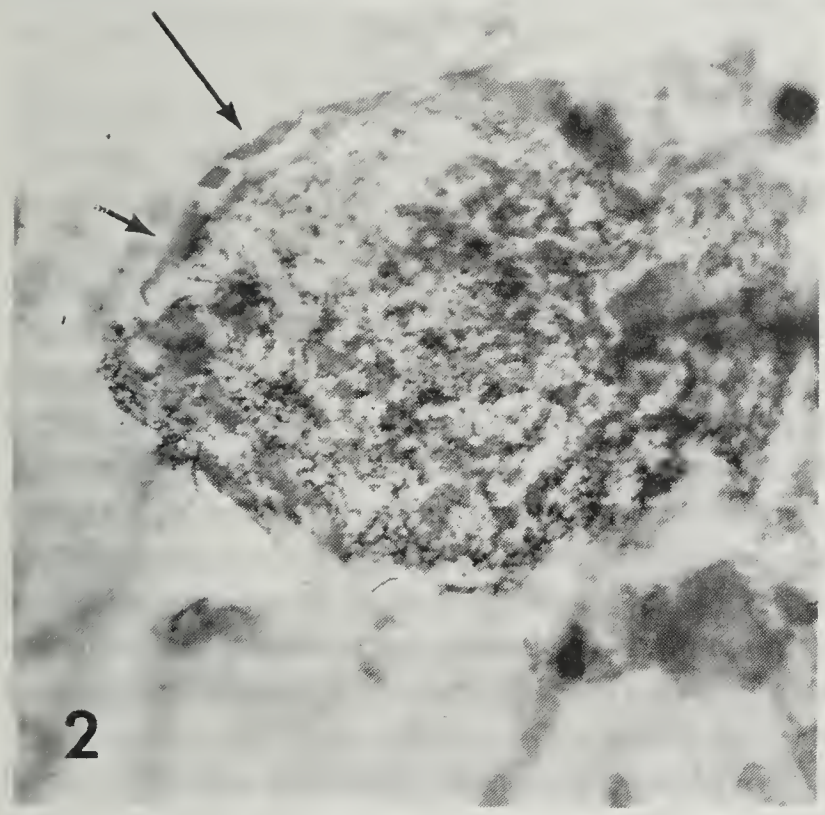

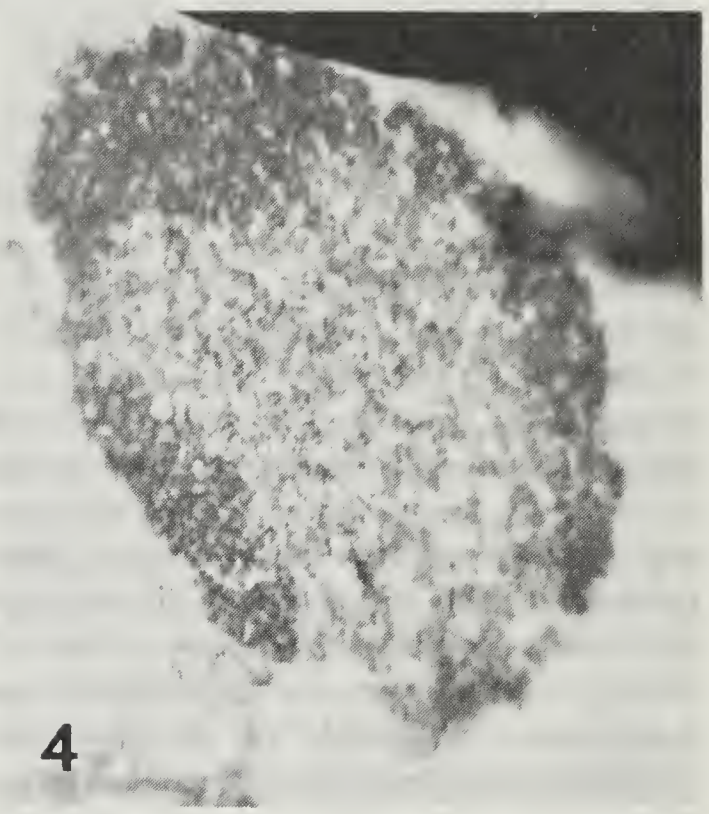

Figure 1. Intact Nuclei Isolated without Detergent. Note the clearly-defined nuclear boundaries (light microscopy, 5400X).

Figure 2. Intact Nucleus Isolated without Detergent, showing Membrane material (arrows); Electron Microscopy (9000X).

Figure 3. Intact Nucleus After Detergent Treatment (light microscopy, 5000X).

Figure 4. Intact Nucleus After Detergent Treatment (electron microscopy, 12000X).

ALLELOPATHIC EFFECTS OF *LYCOPODIUM FLABELLIFORME* SPOROPHYTES

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ABSTRACT

Experiments were conducted to test the effects of *Lycopolium flabelliforme* (Ferns.) Blanch sporophyte material on the germination and growth of seedlings of *Lycopersicum esculentum* Mill. and *Raphanus satival* L. Three different treatments were undertaken using grindate, fresh, and extracts of sporophyte tissue. The grindate treatment produced the greatest inhibitory effects. Further tests indicated that the inhibitory substances were heat stable and concentratable. Column chromatography of extracts at 37.7°C, yielded a crude alkaloid extract with a molecular weight and size near that of glucose. *Lycopersicum esculentum* germination and seeding growth was inhibited by this crude alkaloid extraction.

INTRODUCTION

Allelopathy is defined as any direct or indirect harmful effect by one plant on another through the production of chemical compounds that escape into the environment (Rice, 1974). Many different types of organic compounds have been identified as inhibitors. Evenari (1949) stated that all seeds and fruits known for their high alkaloid content are strong germination inhibitors, and it can be shown that the alkaloids are the main, if not the only cause of inhibition in these cases.

The two genera *Lycopodium* and *Equisetum* are notable exceptions to the fact that alkaloids are rarely found in the lower vascular plants. Manske (1955) reviews much of the early literature concerned with the presence of alkaloids in the genus *Lycopodium*, and found the alkaloids lycopodine, complanatine, bases L2 to L5, obscurine and nicotine in *Lycopodium flabelliforme* (Fern.) Blanch. Later, Curcumelli-Rodostamo and MacLean (1962) identified flabelliformine, and Young and MacLean (1963) identified flabelline.

The present work is concerned with the problem of whether or not inhibitors arise from, and affect the composition of the plants associated with *Lycopodium flabelliforme* colonies. Experiments were conducted to test the effect of sporophyte material on the germination and growth of seedlings of *Lycopersicum esculentum* Mill. (tomato) and *Raphanus sativa* L. (radish). Also determined is the heat stability and molecular size of the inhibitory substance or substances.

MATERIALS AND METHODS

Preparation of Sporophyte Material: Sporophyte material of *Lycopodium flabelliforme* was collected from a colony 2 miles NW of Flat Rock, Crawford County, Illinois (Sect. 36 T6N R12W). Approximately one-third of the collected material was air-dried for 3 days, ground to a coarse grade using a Wiley Mill and placed in an air-tight container (grindate). Another one-third-portion yielded an extract by placing 25 g of sporophytes plus 250 ml of distilled water into a Waring blender and homogenizing for 10 minutes. The solution was then centrifuged at 1500xg for 10 minutes. The supernatant was centrifuged again at 1500xg for 10 minutes. The final supernatant was suction-filtered and placed in a polyethylene bottle (extract). The last one-third portion was sealed fresh in a plastic bag (fresh). All forms were stored in a refrigerator.

Allelopathic Investigations: In three separate studies, using 10 replicates per treatment, 0.25 g of grindate, 0.25 g of fresh material, and 0.10 ml of extract were placed in separate Petri dishes, with 10 ml of distilled water and 4 seeds of *Raphanus sativa* L. (radish) on a disk of Whatman No. 1 filter

paper. A control was prepared in the same way with sporophyte material excluded. The plates were incubated for three days at approximately 27°C. After the incubation period, number of seeds germinated and radicle lengths (mm) were recorded. A ''germinated'' seed possessed a radicle 4 times its own length.

Heat Stability of Allelopathic Substance: Lycopodium extract was subjected to the following test to determine its heat stability, and its ability to be concentrated. The extract material used was collected in September since it was thought that this material would possess the highest inhibitor concentrations.

Test tubes containing one ml of *Lycopodium* extract was placed in boiling water (100°C.) for the following lengths of time; 30 seconds 1, 3, 10, and 30 minutes. After this heat treatment, the test tubes were placed in an ice bath and cooled to room temperature. Extract volume was brought up to 10 ml with distilled water and poured into Petri dishes along with 10 tomato seeds (*Lycopersicum esculentum* Mill.) on a disk of Whatman No. 1 filter paper. Eight control dishes were prepared containing only 10 seeds and 10 ml of distilled water. Percent inhibition and germination was calculated after 5 and 10 days.

Molecular Size of Allelopathic Substance: Column chromatography was used to separate the different molecular sized compounds present in *Lycopodium* extract. Again, the extract was prepared from sporophytes collected in September.

Twenty ml of extract was dehydrated to dryness using a Rotary Evapo-Mix. The dried substance was rehydrated to 1 ml with distilled water, shaken using a Vortex Junior, and then loaded into a column filled with Bio-Gel P-2 (100-200 mesh), as two 0.5 ml portion followed by two 0.5 ml portions of distilled water. Fifteen two ml samples were collected and brought up to a 20 ml volume with distilled water. The solutions were then divided into two 10 ml portions and placed into separate Petri dishes along with 5 radish seeds on a disk of Whatman No. 1 filter paper. Percent germination and radicle length (mm) were recorded after 9 days. An Inhibition Value (I-Value) was calculated after del Moral and Cates (1971), where the magnitude of the I-Value is directly proportional to the inhibitory capacity of the fraction examined.

To determine the molecular size of the substance present in each faction, 0.1 ml of blue dextran/glucose solution was loaded into a column filled with Bio-Gel P-2 and thirty 1 ml fractions were collected. Each fraction was then analyzed for sugar content by adding 3 ml of anthrone, boiling for 10 minutes, cooling to room temperature, and its absorbtion read on a Bausch and Lomb spectronic 20 colorimeter.

Alkaloid Extraction: Alkaloid extraction procedures were adapted from Manske and Marion (1942). After extraction, 1 ml of distilled water was added to 10 ml of the deyhdrated ''crude alkaloid'' and shaken using a Voltex Junior. One ml of this extract was placed with 10 ml of distilled water and 5 tomato seeds on a disk of Whatman No. 1 filter paper in a Petri dish. Plates were allowed to incubate for 9 days at room temperature (27°C.). The number of seeds germinated and radicle lengths were recorded.

Field Observations: The physiognomy of the colonies suggested more abundant growth of herbaceous plants outside of the *Lycopodium* colonies. Four randomly tossed 0.25 m^2 quadrat samples were taken inside, and not more than 5 m outside of the colony. The number of individuals of each species encountered per sample unit were recorded.

RESULTS AND DISCUSSION

Allelopathic Investigations: Results of the allelopathic investigations show that *Lycopodium* sporophyte material does inhibit the germination and growth of radish seedlings under laboratory conditions. Of the forms of sporophyte material used (grindate, extract, fresh), the grindate form had the greatest inhibitory effect. With this treatment the mean radicle length was 4.8 to 5.1 mm while the percent germination varied from 14 to 18%. These results are significant from all other

means at the .05% level (Table 1). Also, mean radicle length of seedlings subjected to extract and fresh sporophyte material was significantly different from the control means in two of the three replicates. The extract results for these experiments are difficult to explain since the extract was prepared from grindate material. Possible explanations are problems with the extraction procedure, and/or low concentrations of inhibitors in these spring collected sporophytes. According to del Moral and Cates (1971), if inhibitors are present in high concentrations in mature tissue, they could inhibit the growth of developing sporophytes. The low inhibition with fresh material is not surprising, since in living material it is quite possible that the inhibitor will not diffuse out of the cells.

Heat Stability of Allelopathic Substance: Results of the heat stability experiment indicates that the inhibitory substance is heat stable and can be concentrated by heating. Five-day readings (Table 2) of the number of seeds germinated revealed about 95-100% inhibition of germination for all lengths of heat treatment, taking control germination as 100%. A ten-day reading was made, but values were not significantly different from the five-day readings (t-test).

Molecular Size of Allelopathic Substance: Molecular size experiments were conducted at two temperatures. When *Lycopodium* extract was analyzed by column chromatography at room temperature (27°C.), no inhibitory effect was observed on seed germination or seedling growth. But when the temperature of the study area accidently reached 37.7°C., an inhibitory effect was observed in fractions 11, 12, and 13 (Table 3). Utilizing a blue dextran/glucose standard curve prepared previous to the experiment and plotted simultaneously, glucose was eluted in fraction 12. This suggests the actual inhibitory substance possesses a molecular size and a molecular weight somewhere close to that of glucose (Mw = 180). Replicates of this experiment at both temperatures were performed, and the results for 37.7°C. are shown in Table 3.

When the temperature of the experimentation area reached 37.7°C. an artificial high temperature stress condition was probably created. Perhaps the inhibitory substance present in *Lycopodium flabelliforme* is effective only under high temperature conditions. Although temperature readings of the colony area were not made, soil surface temperatures in Illinois have been known to reach 37.7°C. Although the test plants were exposed to only one night of high temperature, perhaps this was sufficient to activate the inhibitors present.

Table 1. Mean radicle length (mm) and germination percentages (%G) of radish seeds subjected to 3 treatments in 3 replicates.

Control		Grindate		Extract		Fresh	
Length	%G	Length	%G	Length	%G	Length	%G
49.8	87	5.1*	18	27.5+	87	30.0+	78
45.9	92	4.8	14	34.0+	87	34.2+	82
33.3	85	5.1*	16	30.7	95	30.8	90

* Significantly different at the .05% level from all other means.
+, Significantly different at the .05% level from the controls.

Table 2. Percent germination (%G) and percent inhibition (%I) of tomato seeds growing in *Lycopodium* sporophyte extract subjected to various lengths of heat treatment.

Length of heat	Five days		Ten days	
treatment	%G	%I	%G	%I
30 sec	5.1	94.9	4.5	95.5
1 min	0.0	100.0	9.1	90.9
3 min	0.0	100.0	0.0	100.0
10 min	0.0	100.0	4.5	95.5
30 min	5.1	94.9	9.1	90.9
Control	49.0	0.0	55.0	0.0

Table 3. Inhibition values (I-values) for fractions of *Lycopodium flabelliforme* extracts from column chromatography (del Moral and Cates, 1971). The I-value listed is directly proportional to the degree of inhibition the collected fraction had on radish seed germination and seedling growth. Fractions 1, 2, and 3 served as controls, therefore possess no I-values. This experiment was conducted at 37.7°C. The optical density of each fraction is also given.

		I-vaues			
Fraction	Optical	Seed Germination		Seedling Growth	
Number	Density	Expt. 1	Expt. 2	Expt. 1	Expt. 2
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	.55	0	0	0	0
5	.01	1	0	15	8
6	.04	10	1	19	10
7	.02	0	0	0	0
8	.03	0	0	0	0
9	.01	0	0	0	0
10	.05	0	0	0	0
11	.16	16	17	24	10
12	.49	33	47	13	12
13	.22	55	48	34	33
14	0	22	0	19	8
15	0	10	16	0	16

Alkaloid Extraction: There are many compounds possessing a molecular weight around that of glucose, ie. alkaloids and their perchlorates. Results of the alkaloid extraction experiment infer that a ''crude alkaloid'' fraction does exist in *Lycopodium flabelliforme,* and that this fraction does exhibit some inhibitory effect on tomato seedlings. The data obtained were analyzed using a Student t-test with a 0.1 protection level. Mean lengths of tomato radicles subjected to the ''crude alkaloid'' treatment were significantly shorter than the control means in two replicates. Taking control germination as 100%, a 32% decrease in germination was observed for those seeds subjected to the ''crude alkaloid'' treatment.

Field Observations: Because a slight change in the microenvironment can have a great effect on the inhibitory power of a compound, it cannot be assumed that because an extracted fraction of a plant inhibits another plant under laboratory conditions that this would be the case in the field. Even though a plant might release inhibitory compounds into the soil, several things could occur to render these compounds inactive. According to Muller and Muller (1956) the inhibitory material could be destroyed or altered by soil microflora to yield a harmless compound, or it may never reach a concentration high enough to inhibit surrounding flora, or it may be absorbed by the colloidal components of the soil.

From field observations and sampling (Table 4), it is postulated that *Lycopodium flabelliforme* exhibits an inhibitory effect in the field which tends to produce a large homogenous poplation. Six species of plants were observed growing outside the colony and were absent in the colony, while one species, *Potentilla simplex,* was found both inside and outside the colony. However, there were five times as many individuals outside the colony. *Partenocissus quinquefolia* seemed quite tolerant of any inhibitory substance present, and perhaps even stimulated, as 32 individuals were recorded inside the colony while none were found outside. Two other species (3 individuals) were also found only inside the colony. *Pycnanthemum flexuosum* and *Solidago altissima* seemed the least tolerant as 24 and 14 individuals were recorded outside the colony respectively, and none inside. A total of 4 species and 38 individuals were found inside the colony, while 7 species and 76 individuals, twice that of inside the colony, were recorded outside the colony.

Table 4. The species and the number of plants per square meter inside and outside a *Lycopodium flabelliforme* colony.

Species	Outside Colony	Inside Colony
Achillea millefolium L.	5	0
Aster pilosus Willd.	8	0
Elymus virginicus L.	0	1
Parthenocissus quinquefolia (L) Planch.	0	32
Poa compressa L.	2	0
Potentilla simplex Michx.	15	3
Pycnanthemum flexuosum (Walt.) BSP.	24	0
Rudbeckia hirta L.	8	0
Solidago altissima L.	14	0
Solidago spp. (seedlings)	0	2
Totals	76	38

The allelopathy resulting from alkaloids produced by *Lycopodium flabelliforme* appears to be at least a partial explaination of the expanding homogenous colonies of *L. flabelliforme* in Illinois. This study supports the suggestion by Ebinger (1979) that the allelopathic conditions produced by *L. flabelliforme* were responsible for the homogenous nature of the ground pine colonies.

The introduction and spread of *L. flabelliforme* colonies in Illinois appears to be related to conifer plantings where the ground pine was incorporated in root ball packing materials (Ebinger 1979). Zimmerman and Kucera (1977) found that disturbance of natural ecosystem control mechanisms apparently caused the occurrance of large homogeneous goldenrod populations in Missouri. The relationship between allelopathy and ecosystem disturbance, for *L. flabelliforme* colonies in Illinois and adjacent sites, will be investigated in future studies.

ACKNOWLEDGEMENTS

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NOTES

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EDITORAL NOTE

The ways of an Editor are not, popular to the contrary, based in necromancy and divination. We cannot foretell just what we will receive in the way of manuscripts, nor can we guess what disciplines those writing will reflect. Therefore, it is with particular pleasure that this Editor embarks upon Volume 73 of the Transactions, feeling that the Fates have, indeed, been kind to him. The superb quality of many of the articles will speak for itself throughout this volume year. All members of the Illinois State Academy of Science can take pride in what their journal is reflecting, particularly in primal research, in a very wide spectrum of academic fields ranging from anthropology to zoology.

I have the distinct advantage of seeing the entire volume year laid out before me at one fell swoop, since we are striving mightily to put the journal back on to its original calendar year publication basis. If the gods, the printer and the Postal Service all cooperate, all four numbers of this volume should be published in the near future.

This is particularly important to note, in that these four numbers also mark the end of my editorship. Commencing with Volume 74, the editorship will change. From the supposed ''hinterlands'' of Alaska, I shall be watching with continued interest the evolvement of the **Transactions** and I take this opportunity to thank my Academy colleagues for the cooperation they have evinced over the two year period I have served as Editor, and I wish my successors all success.

Basil C. Hedrick
Editor

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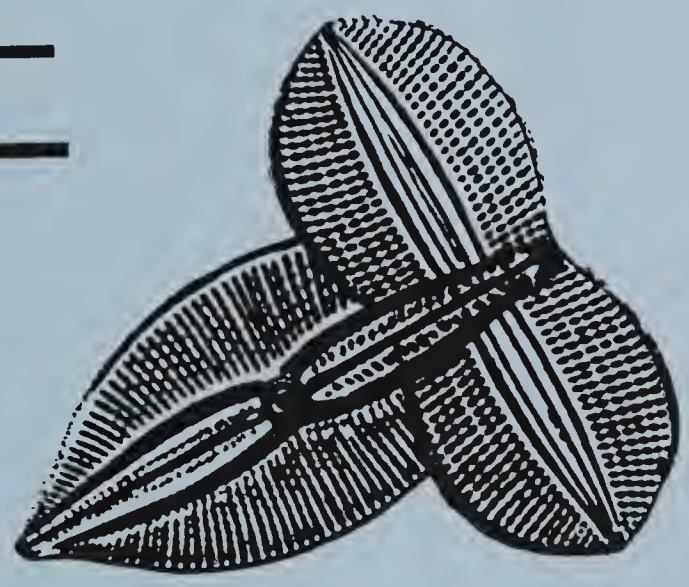

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ERRATUM

Numbers of 3 and 4 of Volume 72 mistakenly carry the date of 1980. They should instead read 1979.

NOTICE

Dr. Basil C. Hedrick has resigned as editor of the Transactions of the Illinois State Academy of Science effective with the final publication of Volume 73 (1980). Beginning with Volume 74 (1981) the editorship will be shared by Dr. Anthony Paparo and Dr. L. Richard Coulson, Southern Illinois University School of Medicine, Southern Illinois University at Carbondale, Carbondale, Illinois 62901. Please address all manuscripts and editorial correspondence to their attention.

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Keys to the Planthoppers, or Fulgoroidea, of Illinois (Homoptera)[1]

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ABSTRACT

Keys to the 9 families, 51 genera and 150 species of Illinois planthoppers, with accompanying illustrations, are presented. Included is a synopsis of the systematic literature of each of the Illinois families and genera.

INTRODUCTION

The superfamily Fulgoroidea contains ca. 7800 species in 20 families (Metcalf 1951). More than 600 species in 11 families occur in America north of Mexico (Metcalf 1936; 1943; 1945; 1946; 1947a,b; 1954a,b; 1957; 1958; hereafter referred to collectively as ''Metcalf's catalogs''); all species studied are phytophagous. The North American planthoppers (the vernacular name was suggested by Metcalf (1920)) can be separated from other adult Homoptera by the location of the antennae ventral to the compound eyes (except in *Bothriocera),* and the presence on the clavus of the forewing of a Y-shaped vein (except in some brachypterous forms (e.g., *Bruchomorpha*)) formed by a combination of the postcubital and first anal veins (Fennah 1944). In other Homoptera, the antennae are anterior to the compound eyes and the clavus does not bear a Y-shaped vein.

Literature on the systematics of North American planthoppers is extensive (e.g., Metcalf's catalogs), and includes taxonomic studies of families (e.g., Doering 1932), tribes (e.g., O'Brien 1971), allied genera (e.g., McDermott 1952), and genera (e.g., Kramer 1973). The majority of studies, however, are scattered descriptions of new species (e.g., Beamer 1947).

Faunal surveys include both keys for identification and/or lists of the fulgoroids occurring in states, Canadian provinces or local regions (see Metcalf's catalogs). Only the accounts of Metcalf (1923) for the eastern United States, Dozier (1928) for Mississippi, Osborn (1938) for Ohio, and Van Duzee (1923) for Connecticut provide keys.

No detailed studies of the Illinois planthopper fauna, except for that of Wilson and McPherson (1980), have been published although several systematic studies have included scattered Illinois records (e.g., Mead 1968). Metcalf (1923) presumably included Illinois in his treatment of the planthoppers of eastern North America although this was not stated. His keys, however, are outdated due to subsequent taxonomic revisions, synonymies, and additions of new species (e.g., Beamer 1946a). Many revisions have relied on extensive use of genitalic characters (e.g., Kramer 1977) making correct identification of many species, using available keys, difficult or impossible.

MATERIALS AND METHODS

Construction of keys was facilitated by the examination of ca. 7700 specimens borrowed from the following Illinois institutions; Illinois Natural History Survey (INHS), Urbana; Field Museum of Natural History, Chicago; Eastern Illinois University, Charleston; Illinois State University, Normal; Illinois State Museum, Springfield; Western Illinois University, Macomb; Northern Illinois University, DeKalb; and Loyola University, Chicago. Additional Illinois specimens deposited in the National Museum of Natural History (NMNH) collection (ca. 300 specimens), and the Insect Collection, Zoology Research Museum, Southern Illinois University at Carbondale (ca. 200 specimens), augmented by local field collecting (ca. 2800 specimens), were also examined. The collection in which specimens are deposited is indicated for those species represented by only 1 or 2 specimens.

[1]Part of a dissertation submitted to Southern Illinois University by the senior author in partial fulfillment of the requirements of the Ph. D. degree in Zoology.

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Use of male genitalic features was necessary to identify species in several families. This generally required removal and clearing of the genitalia in the following manner; 1) the abdomen of a specimen was removed by gently grasping it near the base with a pair of fine jeweler's forceps. If the abdomen was securely attached, the specimen was placed in a syracuse dish of warm water for ca. 30 minutes and the abdomen removed while the specimen was immersed; 2) the abdomen was cleared overnight in a KOH solution by placing it in a well of a 24-cup plastic Falcon MultiWell® plate containing a KOH pellet dissolved in distilled water; 3) after sufficient clearing (generally 12-16 hrs.), the abdomen was placed in distilled water for ca. 10 minutes. For examination, the abdomen was placed in a syracuse dish of glycerine to decrease movement. To examine the aedeagus, it often was necessary to gently push the connectives (of the aedeagus and styles) posteriorly with the tine of a sharp pair of forceps, thus forcing the aedeagus out of the pygofer and into view. The genitalia were positioned for illustrating by placing them on sand grains added to the syracuse dish of glycerine. After examination, the genitalia were placed in a small, plastic genitalia capsule containing a drop of glycerine. The capsule was then closed with a plastic stopper.

Drawings of taxonomic characters were made on tracing paper with the aid of a camera lucida.

RESULTS AND DISCUSSION

Specimens of 9 families, 51 genera and 150 species from Illinois were found in the collections examined. An Illinois distribution map for each species is provided by Wilson (1980).

Keys to most (Ashmead 1889; Dozier 1928; Metcalf 1923; Muir 1923; Osborn 1938; Van Duzee 1907, 1923) or all (Borror et al. 1976, Muir 1930) of the North American fulgoroid families are available and adequate for the majority of Illinois planthoppers. However, some groups are difficult or impossible to identify to family using those keys. For example, derbids are identified in most family keys by the presence of a row of apical spines on the 2nd segment of the metatarsi. Fennah (1952) reported that 2 foreign genera have only 2 apical spines on this segment. We found several Illinois derbids which also have only 2 apical spines on this segment.

Planthopper characters used in the present keys are defined as follows: the vertex or dorsum of the head is bordered anteriorly by the anterior margin, posteriorly by the back of the head, and laterally by the eyes (Muir 1915). The frons extends from the vertex ventrally to the frontoclypeal suture and is bordered laterally by carinate margins, and the clypeus extends from the frons to the beak. The vertex and frons (e.g., *A. conica*), the frons (e.g., *Scolops*), or the frons and clypeus (e.g., *Bruchomorpha*) may be anteriorly produced. Each antenna consists of a 2-segmented base and a distal flagellum. Spines or spine-like processes are elongate, spike-like or needle-like extensions of the tibia (Fig. 90), anal tube (e.g., Fig. 32), or aedeagus (Fig. 65). Teeth in delphacids are minute structures on the metatibial spur (Fig 1) or aedeagus (e.g., Fig. 32). As a matter of preference, we used forewings rather than elytra (Van Duzee 1923) or tegmina (Fennah 1944), hindwings rather than wings (Fennah 1944) and, except for "claval suture" by Metcalf (1913), Fennah's (1944) venation terminology.

Several terms have been used to describe male genitalia. The following are used here because they have been recently or frequently used in the literature. These include pygofer (e.g., Kramer 1979) rather than segment IX (Marks 1951); anal tube (e.g., Flynn 1967), rather than anal flap (e.g., Kramer 1979), anal segment (e.g., Giffard 1921) or segment X (e.g., DuBose 1960); anal style (e.g., Metcalf 1949) rather than segment XI (e.g., DuBose 1960); styles (e.g., Kramer 1979) rather than parameres (e.g., Flynn 1967) or gonoforceps (Marks 1951); and aedeagus (e.g., Kramer 1979) rather than phallobase (e.g., O'Brien 1971). In systematic studies of North American species, female genitalia have either not been used or have been used only to a limited extent (e.g., Doering 1932). In some groups (e.g., *Myndus;* see Kramer 1979), female genitalia apparently lack distinguishing characters.

Characters which pertain only to a particular family or genus are discussed with that taxon.

The discussion of families and genera follows the sequence of the occurrence of each in the keys.

Key to Families

1. Metatibia with a large moveable spur present at the distal end (Fig. 1) . . . . . Delphacidae
1′. Metatibia without a moveable spur at the distal end 2
2. Second segment of metatarsi with a distal row of 3 or more spines 3
2′. Second segment of metatarsi with 2 or fewer distal spines 7
3. Transverse sulcus present near juncture of vertex and frons (Figs. 57, 58); anal area of hindwings with reticulate venation; length over 10 mm . . . . . Fulgoridae
3′. Transverse sulcus lacking at juncture of vertex and frons; anal area of hindwings without reticulate venation; size variable 4
4. Forewings overlapping distally (Fig. 2), resting position almost horizontal . . . . . Achilidae
4′. Forewings not overlapping distally, resting position variable 5
5. Clavus with or without a row of pustules (Fig. 68); if pustules absent, either each antenna partially surrounded by well-developed ventral shelf-like extension on side of head (Fig. 76) or the head is compressed laterally (e.g., Figs. 71-75) . . . . . Derbidae
5′. Clavus without a row of pustules; each antenna partially surrounded by a weakly developed ventral shelf-like extension, or extension absent; head not compressed laterally 6
6. Vertex produced with median length 2 or more times length of eye, or not produced; if not produced, profemora foliaceous . . . . . Dictyopharidae
6′. Vertex not produced, median length less than 2 times length of eye; profemora not foliaceous . . . . . Cixiidae
7. Head compressed laterally; antennal appendages present (Figs. 71-74) . . . . . Derbidae
7′. Head not compressed laterally; antennal appendages absent 8
8. Macropterous; clavus with pustules (pustules may be hidden by waxy powder); forewings with many costal crossveins between costal and subcostal veins (Figs. 105, 106) . . . . . Flatidae

8'. Brachypterous or macropterous; clavus without pustules; forewings with few or no costal crossveins, and lacking subcostal vein 9

9. Macropterous; forewings with reticulate venation . . . . . Acanaloniidae

9'. Brachypterous or macropterous; forewings without reticulate venation . . . . . Issidae

Family Delphacidae Leach

The family Delphacidae is easily separated from other families by the presence of a moveable spur or calcar (Fig. 1) at the apex of each metatibia (Metcalf 1923); this spur is flattened or spike-like and if flattened, may have lateral teeth. It is represented in Illinois by 16 genera and 65 species.

Keys for separating delphacid genera are given by Ashmead (1889), Crawford (1914), Metcalf (1923), Muir (1915), Muir and Giffard (1924), Osborn (1938) and Van Duzee (1897, 1907, 1923). Use of those keys may result in misidentifications because they fail to account for variability in some genera, or because of subsequent taxonomic revisions. The following keys have been designed to handle both problem areas.

Most of the characters used in our keys have been adapted from previous works (e.g., the antennae of *Copicerus*). New characters include the number of teeth on the metatibial spur, and the length of the vertex anterior and posterior to the M-shaped carina.

Key to Genera

1. Antennae elongate, reaching beyond mesonotum; segments laterally flattened and foliaceous . . . . . *Copicerus*

1'. Antennae not elongate, not reaching beyond mesonotum; segments usually cylindrical or subclylindrical but if flattened, then not foliaceous 2

2. Frons with 2 median carinae extending from near clypeal border onto vertex (Fig. 3) 3

2'. Frons with 1 median carina (Fig. 5), sometimes forking in dorsal ⅓ and then continuing onto vertex as 2 carinae (Fig. 6) 4

3. Metatibial spur with a longitudinal row of black-tipped teeth; mesonotum with 3 carinae . . . . . *Macrotomella*

3'. Metatibial spur without a row of teeth; mesonotum with 5 carinae . . . . . *Pentagramma*

4. Metatibial spur with a continuous row of black-tipped teeth 5

4'. Metatibial spur without a continuous row of black-tipped teeth although 3 or 4 scattered, minute black-tipped teeth may occasionally be present 17

5. First antennal segment distinctly flattened (Fig. 4) . . . . . *Stobaera*

5'. First antennal segment cylindrical or subcylindrical but if slightly flattened, then median carina of frons forked in dorsal ⅓ — ¼ (Fig. 6) 6

6. Pronotal lateral carinae extending to, or almost to, posterior border of pronotum (Figs. 7, 9, 10); carinae straight or curved so that apices become parallel to midline 7

6′. Pronotal lateral carinae not extending to posterior border of pronotum, apices well separated from border (Figs. 8, 11); carinae straight or divergently curved with apices curved away from midline 14

7. Metatibial spur with 15 or more black-tipped teeth 8

7′. Metatibial spur with fewer than 15 black-tipped teeth 12

8. Length of vertex subequal to width across base; median carina of frons forked at dorsal ⅓ — ¼, each branch of fork sinuate (Fig. 6) . . . . . *Peregrinus*

8′. Length of vertex greater than width across base (subequal in *Prokelisia*); median carina of frons usually forked at apex but if forked below apex, then each branch of fork not sinuate 9

9. Second antennal segment 3 or more times length of first; lateral borders of ventral ½ of frons subparallel (Fig. 5) . . . . . *Stenocranus*

9′. Second antennal segment less than 3 times length of first; lateral borders of ventral ½ of frons generally outwardly convex 10

10. Each mesonotal lateral carina, at base, closer to apex of pronotal lateral carina than to pronotal median carina (Fig. 7) . . . . . *Megamelus*

10′. Each mesonotal lateral carina, at base ca. midway between the apex of pronotal lateral carina and pronotal median carina, or closer to median carina (Fig. 9) 11

11. Vertex with area anterior to M-shaped carina greater than, or equal to, area posterior to carina (e.g., Fig. 8) . . . . . *Pissonotus* (in part)

11′. Vertex with area anterior to M-shaped carina less than area posterior to carina (Fig. 9) . . . . . *Prokelisia*

12. Vertex with area anterior to M-shaped carina greater than, or equal to, area posterior to carina (e.g., Fig. 8.) . . . . . *Pissonotus* (in part)

12′. Vertex with area anterior to M-shaped carina less than area posterior to carina (Fig. 10); occasionally obscure M-shaped carina located just posterior to apex of inverted V-shaped carinae 13

13. Median length of vertex ca. ¾ that of mesonotum (Fig. 10) . . . . . *Kelisia*

13′. Median length of vertex ca. ½ that of mesonotum . . . . . *Prokelisoidea*

14. Metatibial spur with 15 or more black-tipped teeth 15

14′. Metatibial spur with fewer than 15 black-tipped teeth 16

15. Genital styles of males with 2 or 3 processes (Figs. 30B, 31B) . . . . . *Euides*

15′. Genital styles of males with 1 process or processes lacking (Fig. 33B) . . . . . *Delphacodes* (in part)

16. Pro- and mesofemora distinctly flattened, each 2 times width of tarsi; or head and thorax brown with markedly contrasting yellow carinae . . . . . *Pissonotus* (in part)

16′. Pro- and mesofemora not distinctly flattened, each less than 2 times width of tarsi; head and thorax yellow or brown without markedly contrasting carinae . . . . . *Delphacodes* (in part)

17. Pro- and mesofemora and tibiae distinctly flattened, each at least 2 times width of tarsal segments . . . . . *Phyllodinus*

17′. Pro- and mesofemora and tibiae not distinctly flattened, each less than 2 times width of tarsal segments 18

18. Frons, pronotum, and abdominal tergites with many prominent pits . . . . . *Laccocera*

18′. Frons, pronotum, and abdominal tergites with few or no pits 19

19. Vertex with oblique carinae extending from near midline to lateral or posterior borders (Fig. 11) 20

19′. Vertex without oblique carinae (Fig. 12) . . . . . *Liburniella*

20. Frons ovoid, approximately as wide as long . . . . . *Bakerella*

20′. Frons subrectangular, longer than wide 21

21. Anal tube of male, in lateral view, with posteroventral margin behind spine concave; aedeagus straight or curved (e.g., Figs. 37, 45, 46) . . . . . *Delphacodes* (in part)

21'. Anal tube of male, in lateral view, with posteroventral margin behind spine convex or sharply angled; aedeagus straight (Fig. 54) . . . . . *Chloriona*

Genus *Copicerus* Swartz

Copicerus can be separated from other Illinois delphacids by the large oar-like antennae. *C. irroratus* Swartz, the only Illinois representative of the genus, occurs in the central part of the state; it has been recorded from the eastern U. S. (Metcalf 1943).

Genus *Macrotomella* Van Duzee

Macrotomella can be distinguished from other Illinois delphacids by the 2 median carinae on the frons, 3 carinae on the mesonotum, and the flattened metatibial spur with lateral teeth. *M. carinata* Van Duzee, the only species in the genus (Metcalf 1943), has been recorded from the southeastern U. S. (Metcalf 1943). Only one Illinois specimen was found, and is deposited in the INHS collection.

Genus *Pentagramma* Van Duzee

Pentagramma can be separated from other Illinois delphacides by the 2 median carinae on the frons (Fig. 3), 5 carinae on the mesonotum, and the spike-like metatibial spur which lacks lateral teeth. *P. variegata* Penner, the only Illinois representative of the genus, occurs in the northern part of the state; it has been recorded primarily from the northern U. S. (Penner 1947). A key to species is given by Penner (1947).

Genus *Stobaera* Stål

Stobaera can be separated from other Illinois delphacids by the shape of the 1st antennal segment, which is subtriangle in dorsal view and distinctly flattened in cross-section (Fig. 4), and the thickened metatibial spur which bears lateral teeth. *S. tricarinata* (Say), the only Illinois representative of this genus, occurs statewide; it has been recorded from New York to Florida, and west to California and Oregon (Kramer 1973). A key to species is given by Kramer (1973).

Genus *Peregrinus* Kirkaldy

Peregrinus can be distinguished from other Illinois delphacids by the median carina which is forked at the dorsal ⅓ — ¼ with each branch sinuate (Fig. 6). *P. maidis* (Ashmead), the only species in the genus, occurs worldwide except in Europe (Metcalf 1943) and has been found in central Illinois. The only Illinois specimens found during this study are deposited in the INHS collection, and are brachypterous. All had been collected "on corn in greenhouse". It is not known if these specimens had been imported into Illinois for research or had invaded the greenhouse on their own. However, its reported range includes the eastern U. S. (Metcalf 1943) and, thus, it may occur here naturally.

This species is listed as a pest of corn (*Zea mays* Linnaeus) (Ashmead 1890, Barber and Pepper 1942, Forbes 1905, Muir 1917, Quaintance 1898, Thomas 1914), causing feeding damage and serving as a vector of Yellow Stripe Disease (App 1941).

Genus *Stenocranus* Fieber

Stenocranus can be separated from other Illinois delphacids by the short 1st antennal segment, generally subparallel lateral margins of the frons (Fig. 5), and slender elongate body. Eight species apparently occur in Illinois, but 1 of these, *S. dorsalis* (Fitch), is of questionable occurrence. Three Illinois specimens identified as *S. dorsalis* (1 male, 2 females) are deposited in the NMNH collection. Only males can be identified to species, and the Illinois specimen proved to be *S. sandersoni* Beamer. No additional specimen was found. *S. felti* Van Duzee, which has not been recorded from Illinois, is included in the present key because it has been found in Wisconsin and New Hampshire (Beamer 1946a) and, thus, may occur in Illinois.

Genitalic characters are used to separate the 9 species because features used in earlier keys, such as color patterns (e.g., Beamer 1946a), were found to be too variable. Dozier (1922), whose study is outdated, and Beamer (1946a,b) reviewed the North American species.

Key to Species

1. Spine-like processes on anal tube bifid (Fig. 13) . . . . . *S. felti* Van Duzee
1′. Spine-like processes on anal tube not bifid (Figs. 14-20) 2
2. Spine-like processes on anal tube subequal in length 3
2′. Spine-like processes on anal tube distinctly unequal in length 6
3. Each style usually with a median spine (Fig. 14B); aedeagal process, in lateral view, bent ventrally at apex, much broader in basal ⅓ than at apex (Fig. 14A) . . . . . *S. pallidus* Beamer
3′. Each style without a median spine; aedeagal process, in lateral view, usually not bent ventrally at apex but if bent ventrally then process slender, almost same width throughout its length (Figs. 15-17) 4
4. Spine-like processes on anal tube short and broadly rounded posteriorly at base (Fig. 15) . . . . . *S. sandersoni* Beamer
4′. Spine-like processes on anal tube elongate, not broadly rounded posteriorly at base (Figs. 16, 17) 5
5. Styles broadest in apical ½ (Fig. 16B); aedeagus, in lateral view, straight or slightly sinuate (Fig. 16A); aedeagal process, in ventral view, trifid . . . . . *S. similis* Crawford
5′. Styles broadest in basal ½; aedeagus, in lateral view, dorsally arcuate in basal ½ (Fig. 17); aedeagal process, in ventral view, bifid . . . . . *S. delicatus* Beamer
6. Aedeagal process, in lateral view, broadest in basal ⅔ (e.g., Fig. 18) 7
6′. Aedeagal process, in lateral view, subequal in width throughout its length (Figs. 19, 20) 8
7. Aedeagus, in lateral view, abruptly curved dorsally in basal ½; aedeagal process with apex slightly curved (Fig. 18) . . . . . *S. brunneus* Beamer
7′. Aedeagus, in lateral view, straight, not abruptly curved in basal ½; aedeagal process with apex sharply curved ventrally . . . . . *S. dorsalis* (Fitch)
8. Aedeagal process bifid apically (Fig. 19) sometimes apparent only in ventral view . . . . . *S. unipunctatus* Provancher
8′. Aedeagel process not bifid apically (Fig. 20) . . . . . *S. lautus* Van Duzee

Genus *Megamelus* Fieber

Megamelus can be separated from other Illinois delphacids by the closely aligned pronotal and mesonotal lateral carinae, and the head which is usually anteriorly produced. The males are distinguished by the bulbous appearance of the sides of the pygofer (Figs. 21-25). Five species occur in Illinois; records of *M. palaetus* (Van Duzee) are from Wilson and McPherson (1979a). The following key is adapted from Beamer (1955). Scudder (1964) reviewed the Canadian species.

Key to Species

1. Anal tube, in caudal view, with processes (Figs. 21, 22) 2
1′. Anal tube, in caudal view, without processes (Figs. 23-25.) 3
2. Anal processes, in caudal view, arise from basal ½ of anal tube (Fig. 21) . . . . . *M. davisi* Van Duzee
2′. Anal processes, in caudal view, arise from apical ½ of anal tube (Fig. 22) . . . . . *M. lunatus* Beamer
3. Pygofer, in caudal view, with a prominent knob-like process between styles (Fig. 23A); aedeagus bifid at apex (Fig. 23B) . . . . . *M. metzaria* Crawford
3′. Pygofer, in caudal view, with knob-like process between styles absent or very small; aedeagus not bifid at apex (Figs. 24, 25) 4
4. Aedeagus, in lateral view, long and slender, without processes near apex (Fig. 24B) . . . . . *M. distinctus* Metcalf
4′. Aedeagus, in lateral view, short and thick, with a slender, short process at apex. (Fig. 25B) . . . . . *M. palaetus* (Van Duzee)

Genus *Pissonotus* Van Duzee

Pissonotus is difficult to separate from some other Illinois delphacids because of variation within the genus. The head is narrower than the body and the vertex usually subquadrate (Fig. 8). Most species are glossy with the pronotal carinae usually reaching the hind margin. Nine species occur in Illinois. *P. aphidioides* Van Duzee has been recorded from New York and Manitoba, and *P. dorsalis* Van Duzee from New York and Wisconsin (Morgan and Beamer 1949); thus, both may occur in Illinois.

Color patterns, as used by Morgan and Beamer (1949), correlate well with the genitalic characters except in *P. delicatus* Van Duzee and *P. marginatus* Van Duzee. Morgan and Beamer (1949) reviewed the North American species.

Key to Species

1. First antennal segment black 2
1′. First antennal segment brown 4
2. Forewings with dark brown veins . . . . . *P. niger* Morgan and Beamer
2′. Forewings with yellowish veins 3
3. Frons, on dorsal half, brown with pale yellow spots and partial crossbands; on ventral half, pale yellow . . . . . *P. albovenosus* Osborn
3′. Frons brown, without pale markings . . . . . *P. brunneus* Van Duzee
4. Frons marked with yellow spots and/or partial crossbands 5

4'. Frons not marked with yellow spots and/or partial crossbands 6

5. Apex of forewings with a pale transverse stripe . . . . . *P. flabellatus* (Ball)

5'. Apex of forewings without a pale transverse stripe . . . . . *P. aphidioides* (Van Duzee)

6. Dorsal ½ of frons, entire vertex, and usually anterior portion of pronotum black, markedly contrasting with remainder of light body . . . . . *P. guttatus* Spooner

6'. Frons, vertex, and pronotum usually brown but if black, then remainder of body is also black 7

7. Posterior ½ of pronotum white . . . . . *P. aquilonius* Morgan and Beamer

7'. Posterior ½ of pronotum usually brown or black but if white, then white band less than ½ width of pronotum 8

8. Forewings with a granulate row of seta bearing tubercles on each vein . . . . . *P. piceus* (Van Duzee)

8'. Forewings without a granulate row of seta bearing tubercles on each vein although very fine setae may be present 9

9. Abdomen with a broad, pale longitudinal stripe ca. ½ — ⅔ width of abdomen . . . . . *P. dorsalis* Van Duzee

9'. Abdomen without a broad, pale longitudinal stripe 10

10. Aedeagus, in caudal view, with apical process bifid (Fig. 26) . . . . . *P. delicatus* Van Duzee

10'. Aedeagus, in caudal view, with apical process not bifid . . . . . *P. marginatus* Van Duzee

Genus *Prokelisia* Osborn

Prokelisia can be distinguished from most other Illinois delphacids by its subtriangular vertex. It is similar to *Prokelisoidea salina* (Ball) but can be distinguished by the yellow-gold body, different ratio of vertex to mesonotal length (see key to delphacid genera), and distinctive genitalia (Fig. 55). *P. crocea* (Van Duzee), the only Illinois representative of this genus, occurs in the northern part of the state; it has been recorded from Maine south to Connecticut, and west to North Dakota and New Mexico (Metcalf 1943).

This genus appears in need of revision; there are no keys that adequately separate the 4 North American species.

Genus *Kelisia* Fieber

Kelisia can be separated from other Illinois delphacids by the elongate narrow vertex (Fig. 10), relatively broad head and narrow elongate body. Five species occur in Illinois. Two of these, *K. hyalina* Beamer and *K. retrorsa* Beamer, each represented by 1 female specimen deposited in the INHS and NMNH collections, respectively, and identified by R. H. Beamer, are of doubtful occurrence because positive identification relies on characters of the male genitalia. We found that external characters given in Beamer's keys (1945a, 1951b) do not correlate well with the genitalic features; thus, only genitalic characters were used in the following key. Beamer (1945a, 1951b) included descriptions and illustrations of genitalia in his review of the North American species.

Key to Species

1. Anal tube, in lateral view, with a basal spine-like projection on posterior margin (Fig. 27) . . . . . *K. spinosa* Beamer
1′. Anal tube, in lateral view, without a basal spine-like projection on posterior margin (Figs. 28, 29) 2
2. Aedeagus, in lateral view, with ventral lobe subdivided into several finger-like processes (Fig. 28) . . . . . *K. pectinata* Beamer
2′. Aedeagus, in lateral view, with ventral lobe not subdivided into several finger-like processes but consisting of, at most, 2 processes (Fig. 29) 3
3. Aedeagus, in lateral view, with ventral lobe subdivided into 2 processes (Fig. 29) . . . . . *K. curvata* Beamer
3′. Aedeagus, in lateral view, with ventral lobe not subdivided . . . . . *K. hyalina* Beamer
K. retrorsa Beamer

Genus *Prokelisoidea* McDermontt

Prokelisoidea can be separated from most other Illinois delphacids by the subtriangular vertex. It is similar to *Prokelisia crocea* but can be recognized by the greenish yellow body, different ratio of vertex to mesonotal length (see key to delphacid genera), and distinctive genitalia (Fig. 56). This genus is represented in Illinois by *P. salina,* which occurs in the northern part of the state; it has been recorded heretofore only from the western U. S. (McDermott 1952). *Prokelisoidea* and allied genera were reviewed by McDermott (1952).

Genus *Euides* Fieber

Euides can be separated from other Illinois delphacids by the distinctive genitalia (Figs. 30, 31). Two species occur in Illinois.

The term ''diaphragm armature'' has been used in the following key to refer to any extension of the rim of the diaphragm opening as in *E. weedi* (Van Duzee) (Fig. 30) and some *Delphacodes* spp. (p. 49, Figs. 52, 53). The genitalia of *E. gerhardi* (Metcalf) appear identical to the genitalia of *Nilaparvata wolcotti* Muir and Giffard as illustrated by Muir and Giffard (1924). If examination of the types reveals that they are the same species, the name *gerhardi* Metcalf (1923, 1949) would have priority over *wolcotti* Muir and Giffard (1924). There are no keys that include all of the 5 North American species.

Key to Species

1. Pygofer, in lateral view, with a prominent, hook-like diaphragm armature beneath aedeagal opening (Fig. 30) . . . . . *E. weedi* (Van Duzee)
1′. Pygofer, in lateral view, without a diaphragm armature beneath aedeagal opening (Fig. 31) . . . . . *E. gerhardi* (Metcalf)

Genus *Delphacodes* Fieber

Delphacodes can be separated from other Illinois delphacids by the small size, stout shape and distinctive genitalia (Figs. 32-53). Twenty-four species occur in Illinois. Because data on the distribution of the members of this genus are extremely limited, no attempt has been made to determine which additional species may occur in Illinois. Thus, users of the following key are cautioned to carefully compare the genitalia of their specimens with Figs. 32-53. If there is doubt as to the identity of a specimen, the descriptions and illustrations of Beamer (1946c; 1947; 1948a,b,c; 1950a; 1951a), DuBose (1960), Metcalf (1949), and Muir and Giffard (1924) should be consulted.

Beamer (1946c; 1947; 1948a,b,c; 1950a; 1951a), described ca. ½ of the 116 North American species but did not provide keys. None of the available keys (e.g., Metcalf 1923) use genitalic characters except for that of DuBose (1960) to the North Carolina *Delphacodes*.

We identified several Illinois specimens, deposited in the Eastern Illinois University collection, as *D. mcateei* Muir and Giffard on the basis of the illustration of the aedeagus provided by Muir and Giffard (1924). The genitalia of another specimen, deposited in the INHS collection and identified by Beamer as *D. sagae* Beamer, were also similar to the *D. mcateei* illustration of Muir and Giffard (1924). If examination of the types reveals that they are the same species, the name *mcateei* Muir and Giffard (1924) would have priority over *sagae* Beamer (1946c, 1947).

Three Illinois specimens, deposited in the INHS collection, were identified by Beamer as *D. magna* (Crawford). However, their genitalia (Fig. 48) did not resemble the illustration of *D. magna* given in Muir and Giffard (1924) and we found Muir and Giffard's illustrations of genitalia to be accurate. Furthermore, the genitalia of the 3 specimens did not resemble those of any species of *Delphacodes* illustrated by Beamer (1946c; 1947; 1948a,b,c; 1950a; 1951a), DuBose (1960), Metcalf (1949) or Muir and Giffard (1924). Thus, those specimens may represent an undescribed species. Nevertheless, since no other name was available, we have use *D. magna* in the key to refer to them.

One Illinois female specimen, deposited in the INHS collection, was identified by Beamer as *D. trimaculata* Beamer. Male genitalia were illustrated by Beamer (1948a).

The genitalia of *D. parvula* (Ball) and *D. rotundata* (Crawford) are similar. The shape of the diaphragm armature (defined in the discussion of *Euides*) appears to be the most obvious difference and is used here to separate the 2 species (Figs. 51, 52). Several male *D. parvula* were examined. However, only 1 male *D. rotundata,* deposited in the Eastern Illinois University collection, was found and, thus, variability of the armature shape in this species is unknown.

Key to Species

1. Anal tube with paired spine-like or knob-like processes visible in lateral view (Figs. 32-46) 2

1′. Anal tube without paired spine-like or knob-like processes visible in lateral view (Figs. 47-53) although a small tooth or medially directed spine-like processes may be visible in caudal view (Fig. 48B) 16

2. Anal tube with elongate, dorsally directed spine-like processes originating from posteroventral margin (Fig. 32) . . . . . *D. andromeda* (Van Duzee)

2′. Anal tube without elongate, dorsally directed spine-like processes originating from posteroventral margin (Figs. 33-46) 3

3. Style, in ventral view, with a median spine at base (Fig. 33B) . . . . . *D. basivitta* (Van Duzee)

3'. Style, in ventral view, without a median spine at base although a tubercle may be present or inner angle at base may be acute 4

4. Aedeagus, in lateral view, with a pair of anterodorsally directed processes apically (Fig. 34); aedeagus without teeth . . . . . *D. analis* (Crawford)

4'. Aedeagus, in lateral view, without anterodorsally directed processes apically; aedeagus with or without teeth (Figs. 35-46) 5

5. Aedeagus, in lateral view, constricted in apical ⅓ — ¼ (Fig. 35) . . . . . *D. atrata* Osborn

5'. Aedeagus, in lateral view, not constricted in apical ⅓ — ¼ (Figs. 36-46) although may be hook-like at apex (Fig. 43) 6

6. Aedeagus, in lateral view, markedly curved ventrally, almost forming a right angle (Fig. 36) . . . . . *D. pellucida* (Fabricius)

6'. Aedeagus, in lateral view, usually straight or S-shaped but if curved ventrally, then forming greater than a right angle (Figs. 37-46) 7

7. Aedeagus, in lateral view, with lateral teeth (Figs. 37-43) 8

7'. Aedeagus, in lateral view, without lateral teeth although dorsal or ventral teeth may be present (with ventrolateral teeth in *D. foveata)* (Figs. 44-46) 14

8. Aedeagus, in lateral view, straight or slightly sinuate (Figs. 37-39) 9

8'. Aedeagus, in lateral view, curved ventrally or S-shaped (Figs. 40-43) 11

9. Aedeagus, in lateral view, with basal portion expanded into a large, dorsal granulate lobe (Fig. 37) . . . . . *D. hyalina* Beamer

9'. Aedeagus, in lateral view, with basal portion not expanded into a large, dorsal granulate lobe (Figs. 38, 39) 10

10. Anal tube, in lateral view, with spine-like process elongate, reaching level of ventral margin of anal tube (Fig. 38) . . . . . *D. puella* (Van Duzee)

10'. Anal tube, in lateral view, with spine-like process short, less than ½ the distance to the level of ventral margin of anal tube (Fig. 39) . . . . . *D. pacifica* (Crawford)

11. Aedeagus, in lateral view, S-shaped (Fig. 40) . . . . . *D. alexanderi* (Metcalf)

11'. Aedeagus, in lateral view, curved ventrally (Figs. 41-43) 12

12. Aedeagus, in lateral view, with a lobe on the ventral margin in basal ½ (Fig. 41) . . . . . *D. mcateei* Muir and Giffard
D. sagae Beamer

12'. Aedeagus, in lateral view, without a lobe on the ventral margin in basal ½ although a small tubercle may be present (Figs. 42, 43) 13

13. Aedeagus, in lateral view, with a lateral keel bearing teeth (Fig. 42) . . . . . *D. nitens* Muir and Giffard

13'. Aedeagus, in lateral view, without a lateral keel bearing teeth (Fig. 43) . . . . . *D. perusta* Beamer

14. Aedeagus, in lateral view, curved ventrally, teeth restricted to ventral margin (Fig. 44) . . . . . *D. dolera* (Spooner)

14'. Aedeagus, in lateral view, straight or slightly sinuate, teeth restricted to ventrolateral and/or dorsal margins (Figs. 45, 46.) 15

15. Anal tube, in lateral view, with process short and claw-like, less than 2 times as long as wide (Fig. 45) . . . . . *D. foveata* (Van Duzee)

15'. Anal tube, in lateral view, with process elongate and spine-like, more than 4 times as long as wide (Fig. 46) . . . . . *D. propinqua* (Fieber)

16. Aedeagus, in lateral view, with 1 or 2 large, dorsally directed process or processes (Figs. 47, 48A) 17

16'. Aedeagus, in lateral view, without dorsally directed processes (Figs. 49-53) 18

17. Aedeagus, in lateral view, with 2 dorsally directed processes; aedeagal teeth absent (Fig. 47) . . . . . *D. laminalis* (Van Duzee)

17'. Aedeagus, in lateral view, with 1 dorsally directed process; aedeagal teeth present or absent (Fig. 48A) . . . . . *D. magna* (Crawford)

18. Aedeagal teeth present (Figs. 49-52) 19

18'. Aedeagal teeth absent (Fig. 53) 22

19. Aedeagus, in lateral view, with basal ½ much wider than apical ¼ — ½ (Figs. 49, 50) 20

19'. Aedeagus, in lateral view, with basal ½ ca. as wide as apical ½ (Figs. 51, 52) 21

20. Aedeagus, in lateral view, with at least apical ⅓ narrower than basal ½; apex rounded or pointed (Fig. 49) . . . . . *D. campestris* (Van Duzee)

20'. Aedeagus, in lateral view, with at most apical ¼ narrower than basal ½; apex subtruncate (Fig. 50) . . . . . *D. lutea* Beamer

21. Pygofer, in lateral view, with posterior margin of diaphragm armature almost vertical (Fig. 51) . . . . . *D. parvula* (Ball)

21'. Pygofer, in lateral view, with posterior margin of diaphragm armature sloping posteroventrally (Fig. 52) . . . . . *D. rotundata* (Crawford)

22. Aedeagus, in lateral view, curved ventrally (Fig. 53) . . . . . *D. lutulenta* (Van Duzee)

22'. Aedeagus, in lateral view, almost straight . . . . . *D. trimaculata* Beamer

Genus *Phyllodinus* Van Duzee

Phyllodinus can be separated from other delphacids by the foliaceous pro-and mesofemora and tibiae, and the metatibial spur which lacks lateral teeth. *P. nervatus* (Van Duzee) which has not been recorded from Illinois, is included in the key because it has been found in New York, Michigan and South Dakota (Morgan and Beamer 1949) and, thus, may occur in Illinois. Morgan and Beamer (1949) included *Phyllodinus* in their revision of *Pissonotus* and allied genera.

Genus *Laccocera* Van Duzee

Laccocera can be separated from other delphacids by the many large circular pits on the head, thorax and abdomen. *L. vittipennis* Van Duzee, which has not been recorded from Illinois, is included in the key because it has been found in 13 states, including New York, Michigan and Minnesota (Penner 1945), and, thus, may occur in Illinois. A key to species is provided by Penner (1945) and Scudder (1963).

Genus *Liburniella* Crawford

Liburniella can be separated from other Illinois delphacids by the white mid-dorsal stripe on the head and thorax, the dark patterned forewings, and the lack of oblique carinae on the vertex (Fig. 12). *L. ornata* (Stål), the only Illinois representative of this genus, occurs statewide; it has been found throughout the eastern U. S. (Metcalf 1943).

Genus *Bakerella* Crawford

Bakerella can be separated from other Illinois delphacids by the ovoid frons. This genus is apparently represented in Illinois by *B. muscotana* Beamer and B. *rotundifrons* Beamer, but we were unable to confirm the presence of either species. Two Illinois specimens which had been identified by Beamer as *B. muscotana* and deposited in the INHS collection, were missing from their points. An Illinois female specimen identified as *B. rotundifrons* by Beamer is deposited in the INHS collection; however, only males can be positively identified to species (Beamer 1945b, 1946b, 1950b). No other Illinois specimen of either species was found. The North American species were reviewed by Beamer (1945b, 1946b, 1950b).

Genus *Chloriona* Fieber

Chloriona can be separated from the other Illinois delphacids by the distinctive genitalia (Fig. 54). *C. slossoni* (Ball) is the only Illinois representative of the genus. The only specimen seen during this study was collected in east central Illinois and is deposited in the INHS collection. *C. slossoni* has previously been recorded from the southeastern U. S. (Metcalf 1943).

Family Fulgoridae Dumeril

The family Fulgoridae can be distinguished from other Illinois families by the presence of the transverse sulcus at the juncture of the vertex and frons (Figs. 57, 58), reticulate anal area of the hindwing, and the large size of the various species (>10 mm). It is represented in Illinois by 2 genera with 1 species each.

Key to Genera

1. Vertex produced anteriorly, anterior margin broadly rounded, median length subequal to that of pronotum (Fig. 57) . . . . . *Cyrpoptus*

1'. Vertex not produced anteriorly, anterior margin subtruncate, median length less than that of pronotum (Fig. 58) . . . . . *Poblicia*

Genus *Cyrpoptus* Stål

Cyrpoptus can be separated from *Poblicia* by the characters given in the key. *C. belfragei* Stal, the only Illinois representative of the genus, occurs in the southern part of the state; it has been recorded from the southeastern and south central U. S. (Kramer 1978). A key to the species of *Cyrpoptus* is provided by Kramer (1978).

Genus *Poblicia* Stål

Poblicia can be separated from *Cyrpoptus* by the characters given in the key. *P. fuliginosa* Olivier, the only Illinois representative of this genus, occurs in the southern part of the state; it has been most frequently recorded from the southern U. S. (Metcalf 1947a).

Family Achilidae Stål

The family Achilidae can be distinguished from other Illinois families by the greatly overlapping forewings (Figs. 2, 59-61). It is represented in Illinois by 3 genera and 8 species. Fennah (1950) revised the world genera. The following key is adapted from O'Brien (1971).

Key to Genera

1. Costal cell greater than ¼ width of forewing (Fig. 59); pronotum with lateral area adjacent to eye at least as wide as eye . . . . . *Epiptera*

1'. Costal cell less than ¼ width of forewing (Figs. 60, 61); pronotum with lateral area adjacent to eye, if visible, much narrower than eye 2

2. Forewing with subcostal cell widened posteriorly (Fig. 60) . . . . . *Catonia*

2'. Forewing with subcostal cell narrow throughout its length (Fig. 61) . . . . . *Synecdoche*

Genus *Epiptera* Metcalf

Epiptera can be separated from other Illinois achilids by the relatively wide costal cell of the forewing (Fig. 59) and by the large and flattened appearance of the body. The genus is represented in Illinois by 2 species. *E. pallida* (Say) has been recorded from New York south to Florida, and west to California and Alberta (Metcalf 1947b) and, thus, may occur in Illinois. The Canadian species were reviewed by Beirne (1950b).

Key to Species

1. Face (frons and clypeus) and thoracic pleura with a continuous, pale wide band; forewings very dark brown; costal margin of forewings and

posterior tip of mesonotum with yellow markings . . . . . *E. opaca* (Say)

1′. Face (frons and clypeus) with pale band absent; costal margin of forewings and posterior tip of mesonotum without yellow markings 2

2. Frons and clypeus brown with pale mottling . . . . . *E. variegata* (Van Duzee)

2′. Frons and clypeus brown but without pale mottling . . . . . *E. pallida* (Say)

Genus *Catonia* Uhler

Catonia can be separated from other Illinois achilids by the relatively narrow costal cell and posteriorly broadened subcostal cell of the forewing (Fig. 60). This genus is represented in Illinois by 4 species. *C. bicinctura* Van Duzee has been recorded from Michigan south to Florida and Texas, and *C. lunata* Metcalf from New Jersey south to Florida and west to Texas and Kansas (O'Brien 1971); thus, both may occur in Illinois. The following key is modified from that of O'Brien (1971) who provided keys to the species in America north of Mexico.

Key to Species

1. Frons with 2 dark bands, dorsal band mottled and lighter than ventral band (Fig. 62) . . . . . *C. nava* (Say)

1′. Frons with or without 2 dark bands but if bands present, then dorsal band not mottled (Figs. 63, 64) 2

2. Frons with ventral dark band reaching and extending along frontoclypeal suture for its entire length (Fig. 63) . . . . . *C. bicinctura* Van Duzee

2′. Frons with ventral dark band either not reaching or, if reaching, not extending along frontoclypeal suture for its entire length, or frons unbanded (Fig. 64) 3

3. Frons with pale band at frontoclypeal suture extending to lateral margins of frons (Fig. 64), or frons unbanded; aedeagus without a dorsally extending lobe on dorsal margin (Figs. 65, 66) 4

3′. Frons with pale band at frontoclypeal suture short, not extending to lateral margins of frons, or frons unbanded; aedeagus with dorsally extending lobe on dorsal margin (Fig. 67) 5

4. Frons with pale brown bands or unbanded; aedeagus with 2nd pair of spines subequal in length to 1st (Fig. 65) . . . . . *C. pumila* Van Duzee

4′. Frons usually with very dark brown bands (Fig. 64); aedeagus with 2nd pair of spines much shorter than 1st (Fig. 66) . . . . . *C. cinctifrons* (Fitch)

5. Aedeagus with 2nd pair of spines weakly developed and much shorter than 1st (Fig. 67) . . . . . *C. carolina* Metcalf

5'. Aeadeagus with 2nd pair of spines subequal in length to 1st . . . . . *C. lunata* Metcalf

Genus *Synecdoche* O'Brien

Synecoche can be separated from other Illinois achilids by the relatively narrow costal and subcostal cells. This genus is represented in Illinois by 2 species. *S. dimidiata* (Van Duzee), which has not been recorded from Illinois, is included in the following key because it is found from Ontario south to Florida, and west to Ohio (O'Brien 1971). The following key is modified from that of O'Brien (1971) who provided keys to the species in America north of Mexico.

Key to Species

1. Forewings with many incomplete crossveins, giving wings a pustulate appearance; frons and clypeus pale, frons mottled at level of compound eyes . . . . . *S. grisea* (Van Duzee)
1'. Forewings without incomplete crossveins; frons with large dark spots or bands or completely dark 2
2. Frons completely dark . . . . . *S. dimidiata* (Van Duzee)
2'. Frons pale with 4 subrectangular dark areas . . . . . *S. impunctata* (Fitch)

Family Derbidae Spinola

The family Derbidae can be distinguished from other Illinois families by either a row of pustules on the clavus of the forewing (e.g., Fig. 68), extensions of the side of the head beneath the antennae (e.g., Fig. 76), or a laterally flattened head (e.g., Figs. 71-75). It is represented in Illinois by 11 genera and 29 species.

Keys to the subfamilies, tribes and some genera are given by Metcalf (1938) and Dozier (1928). Keys to genera are given by Fennah (1952), Metcalf (1923) and Osborn (1938).

Key to Genera

1. Hindwings less than ½ length of forewings and barely extending beyond abdomen . . . . . *Euklastus*
1'. Hindwings more than ⅔ length of forewings and extending at least ½ their length beyond abdomen 2
2. Pronotum with an anterolateral, scroll-like extension partially surrounding base of each antenna 3
2'. Pronotum without an anterolateral, scroll-like extension partially surrounding base of each antenna although an extension of the head beneath each antenna may be present (Fig. 76) 4
3. Forewings white; length from head to apex of forewings 7 mm or more . . . . . *Neocenchrea*
3'. Forewings light brownish with brown stripe along basal ⅓ — ½ of costal margin; length from head to apex of forewings 6 mm or less . . . . . *Syntames*
4. Claval suture usually extending to wing margin but if fading distally, then

not separated from margin by an elongate cell (Fig. 68) 5

4'. Claval suture not extending to wing margin, separated from margin by an elongate cell (Figs. 69, 70) 6

5. Head with a large, laterally produced extension beneath each antenna (Fig. 76) . . . . . *Cedusa*

5'. Head without a laterally produced extension beneath each antenna . . . . . *Patara*

6. Antennae with appendages (Figs. 71-74) 7

6'. Antennae without appendages 9

7. Head, in lateral view, broadly rounded anteriorly (Figs. 71, 72) . . . . . *Shellenius*

7'. Head, in lateral view, angulate anteriorly (Figs. 73, 74) 8

8. Head, in lateral view, with dorsal margin sinuate (Fig. 73) . . . . . *Apache*

8'. Head, in lateral view, with dorsal margin nearly straight (Fig. 74) . . . . . *Otiocerus*

9. Forewings with a flap-like extension of costa near base (Fig. 75) . . . . . *Sayiana*

9'. Forewings without a flap-like extension of costa near base 10

10. Forewings with an apical row of 8 or more similarily-sized adjacent cells (Fig. 69) (*Amalopota fitchi* with variable number of cells) . . . . . *Amalopota*

10'. Forewings with an apical row of 5 or fewer similarly-sized adjacent cells (Fig. 70) . . . . . *Anotia*

Genus *Euklastus* Metcalf

Euklastus can be separated from other Illinois derbids by the short hindwings and recurved venation of the forewings (Metcalf 1923). *E. harti* Metcalf, the only species in the genus, occurs in southern Illinois; it has also been recorded from North Carolina (Ball 1928). We have included this species in *Euklastus* even though some authors (e.g., Ball 1928, Fennah 1952) feel that it may belong in *Sikaiana;* to our knowledge, the genotypes have not been compared.

Genus *Neocenchrea* Metcalf

Neocenchrea can be separated from most other Illinois derbids by the scroll-like extension of the pronotum, which surrounds the base of each antenna, and from *Syntames* by the white forewings. *N. heidemanni* (Ball), the only Illinois representative of the genus, occurs in the southern part of the state; it has been recorded from the eastern U. S. (Metcalf 1945). A key to species is given by Metcalf (1938).

Genus *Syntames* Fowler

Syntames can be separated from most other Illinois derbids by the scroll-like extension of the pronotum and from *Neocenchrea* by the brownish forewings. The only Illinois representive of the genus, *S. uhleri* (Ball), occurs in the southern part of the state; it has been recorded from the eastern U. S. (Metcalf 1945). A key to species is given by Metcalf (1938).

Genus *Cedusa* Fowler

Cedusa can be separated from other Illinois derbids by the generally purple to brownish coloration and the lateral extension of the head beneath each antenna (Fig. 76). Eight species occur in Illinois. In addition, a specimen of *C. redusa* McAtee from Kentucky was found in the INHS collection and is included in the following key. Otherwise, no attempt was made to determine which species may occur in Illinois.

The 9 species included in the key are similar in external characters, except for *C. maculata* (Van Duzee) (see following key), thus necessitating use of male genitalia. The aedeagus (e.g., Fig. 80) consists of a basal shaft and apical flagellum which is folded back upon the shaft. The asymmetrical flagellum often bears spines useful in identification.

The genus has been reviewed by Caldwell (1944a), McAtee (1924), Muir (1913) and Flynn (1967). The following key is adapted from Flynn (1967).

Key to Species

1. Forewings pale with distinct light brown markings in cells. . . . . *C. maculata* (Van Duzee)
1'. Forewings usually dark but if pale, then without markings in cells 2
2. Shaft of aedeagus with projections originating in basal ½ (Fig. 77) . . . . . *C. bedusa* McAtee
2'. Shaft of aedeagus without projections originating in basal ½ (Figs. 78-84). 3
3. Styles, in ventral view, with a deep indentation on median margin in basal ½ (Fig. 79B) 4
3'. Styles, in ventral view, without a deep indention on median margin in basal ½ although margin may be sinuate (Figs. 80B, 82B) 5
4. Aedeagal flagellum, in lateral view of right side, with horizontal process bearing teeth (Fig. 78) . . . . . *C. kedusa* McAtee
4'. Aedeagal flagellum, in lateral view of right side, with horizontal process lacking teeth (Fig. 79A) . . . . . *C. incisa* (Metcalf)
5. Aedeagal flagellum, in lateral view of right side, with a bifid process at base (Figs. 80A, 81) 6
5'. Aedeagal flagellum, in lateral view of right side, without a bifid process at base (Figs. 82-84.) 7
6. Aedeagal flagellum, in lateral view of right side, with 3 dorsally directed processes, 2 of which originate from apex of flagellum (Fig. 80A) . . . . . *C. australis* (Metcalf)
6'. Aedeagal flagellum, in lateral view of right side, with 2 dorsally directed processes, neither of which originates from apex of flagellum (Fig. 81) . . . . . *C. redusa* McAtee
7. Styles with apical hook (e.g., Fig. 80B) 8
7'. Styles without apical hook (Fig. 82B) . . . . . *C. edentula* (Van Duzee)
8. Aedeagal flagellum, in lateral view of right side, with a dorsoanteriorly

directed scrool-like process, a slender, curved horizontal process arising from middle of flagellum, and a shorter straight process arising from apex (Fig. 83) . . . . . *C. vulgaris* (Fitch)

8'. Aedeagal flagellum, in lateral view of right side, without either a dorso-anteriorly directed scroll-like process or a horizontal process arising from middle of flagellum, but with a slender elongate curved process arising from apex (Fig. 84) . . . . . *C. obscura* (Ball)

Genus *Patara* Westwood

Patara can be separated from other Illinois derbids by its dark reddish color and the presence of 4 cells between the media and cubitus of the forewing (Fig. 68). *P. vanduzei* Ball, the only Illinois respresentative of this genus, occurs in the southern part of the state; it has been recorded from the eastern U. S. (Metcalf 1945).

Genus *Shellenius* Ball

Shellenius can be separated from other Illinois derbids by the broadly rounded, laterally flattened head and presence of antennal appendages (Figs. 71, 72). Two species occur in Illinois. Keys to species are provided by Ball (1928) and McAtee (1923).

Key to Species

1. Head, in lateral view, curved dorsally (Fig. 71) . . . . . *S. schellenbergii* (Kirby)

1'. Head, in lateral view, not curved dorsally (Fig. 72) . . . . . *S. ballii* (McAtee)

Genus *Apache* Kirkaldy

Apache can be separated from other Illinois derbids by the acuminate, laterally flattened head which is sinuate dorsally, the presence of antennal appendages (Fig. 73), and its large size and reddish color. *A. degeerii* (Kirby), the only Illinois representative of this genus, occurs statewide; it has been recorded from the eastern and central U. S. (Metcalf 1945).

Genus *Otiocerus* Kirby

Otiocerus can be separated from other Illinois derbids by the angulate apex of the head and the presence of antennal appendages (Fig. 74). Six species occur in Illinois. The species are presently separated by the color patterns on the head and forewings (Ball 1928, McAtee 1923), but these characters seem to be unreliable. For example, specimens identified as *O. signoretii* Fitch, deposited in the Eastern Illinois University and INHS collections, proved to be females of *O. stollii* Kirby. This genus is apparently in need of revision.

Key to Species

1. Forewings whitish, almost all cells containing a brown spot or spots 2

1'. Forewings yellowish or reddish, usually few cells with spots 3

2. Forewings with a discontinuous brown stripe extending from apex of clavus obliquely across wing . . . . . *O. francilloni* Kirby

2′. Forewings without a discontinous stripe . . . . . *O. abbotii* Kirby
3. Forewings with 6 or more apical cells with a spot near outer margin 4
3′. Forewings with 5 or fewer apical cells with a spot near outer margin 5
4. Head, in lateral view, with a black mark at or near apex (Fig. 74) . . . . . *O. wolfii* Kirby
4′. Head, in lateral view, without a black mark at or near apex . . . . . *O. amyotii* Fitch
5. Forewings with several spots, color dark red without a stripe (males) or yellowish with a dull brownish stripe extending from along clavus and branching posteriorly (females) . . . . . *O. stollii* Kirby
5′. Forewings without spots, color pale yellow with a bright reddish stripe extending along clavus and then branching posteriorly . . . . . *O. coquebertii* Kirby

Genus *Sayiana* Ball

Sayiana can be separated from other Illinois derbids by the whitish color, costal extension on the forewings, and large antennae (Fig. 75). *S. sayi* (Ball), the only species in the genus (Metcalf 1945), occurs in the southern and central parts of Illinois; it has been recorded from the eastern U. S. (Metcalf 1945).

Genus *Amalopota* Van Duzee

Amalopota can be separated from other Illinois derbids by the laterally flattened head, the absence of antennal appendages, and, in *A. mcateei* Dozier and *A. uhleri* Van Duzee, by an apical row of 8 or more similarly-sized adjacent cells on the forewing (Fig. 69). *A. fitchi* Van Duzee, in which the number of adjacent cells appears to be variable, is similar in general appearance to some *Anotia* spp. but can be separated from them and other species of *Amalopota* by the dark brown patterned forewings (illustrated by Metcalf (1923)). Three species occur in Illinois. Keys for separating the species of *Amalopota* are given by Dozier (1928) and Metcalf (1923). Fennah (1952) believed that *Amalopota* and *Anotia* are synonymous. Both appear in need of revision.

Key to Species

1. Forewings with brown or red in apical ½ 2
1′. Forewings without brown or red in apical ½ . . . . . *A. mcateei* Dozier
2. Forewings with a broad, pale transverse band in middle . . . . . *A. uhleri* Van Duzee
2′. Forewings without a broad, pale transverse band in middle . . . . . *A. fitchi* Van Duzee

Genus *Anotia* Kirby

Anotia can be separated from other derbids by the laterally flattened head, absence of antennal appendages, and presence of an apical row of 5 or fewer similarly-sized adjacent cells on the forewing (Fig. 70) (except for *A. fitchi;* see discussion under *Amalopota).* Four species occur in Illinois.

The species of *Anotia* are presently separated by color patterns on the abdomen and forewings (e.g., Metcalf 1923, 1938). However, specimens we identified as *A. burnetii* Fitch, on the basis of dark markings on the abdomen, have differently shaped styles indicating that at least 2 species may have a dark abdomen.

Key to Species

1. Abdomen with dark markings dorsally . . . . . *A. burnetti* Fitch
1′. Abdomen without dark markings dorsally 2
2. Apical border of forewings with distinct dark spots in cells . . . . . *A. bonnetii* Kirby
2′. Apical border of forewings without distinct dark spots in cells 3
3. Forewings with some dark veins . . . . . *A. kirkaldyi* Ball
3′. Forewings without dark veins, although veins may be bordered by dark brown . . . . . *A. westwoodii* Fitch

Family Dictyopharidae Spinola

The family Dictyopharidae can be distinguished from other Illinois families by the prolongation of the head, except for *Phylloscelis* which is characterized by foliaceous profemora. It is represented in Illinois by 4 genera and 8 species. Keys for separating the genera are given by Dozier (1928), Metcalf (1923) and Osborn (1938); Gibson's (1917) review of the genus *Dictyophara* included species in several currently recognized dictyopharid genera.

Key to Genera

1. Profemora foliaceous; vertex not produced anteriorly, median length less than 2 times length of eye . . . . . *Phylloscelis*
1′. Profemora not foliaceous; vertex greatly produced anteriorly, median length 2 or more times length of eye 2
2. Forewings opaque, brownish or grayish; body brown . . . . . *Scolops*
2′. Forewings translucent, green-hyaline; body green 3
3. Vertex with median length ca. 2 times length of eye . . . . . *Nersia*
3′. Vertex with median length at least 4 times length of eye . . . . . *Rhynchomitra*

Genus *Phylloscelis* Germar

Phylloscelis can be separated from other Illinois dictyopharids by the foliaceous profemora and beetle-like appearance. Only *P. atra* Germar and *P. pallescens* Germar occur in Illinois. *P. atra* has 2 color forms, 1 of which is all black; the other, 'var. *albovenosa*' (Metcalf 1945), is black except for the yellow pronotum and yellowish veins. The genus was reviewed by Ball (1930). The cranberry toadbug, *P. rubra* Ball, which occurs in the eastern U.S., causes feeding damage to cranberries (*Vaccinium macrocarpon* Aiton) (Ball 1930, Scammell 1917, Sirrene and Fulton 1914).

Key to Species

1. Forewings with 3 or 4 longitudinal veins that may fork distally, color black or with black and yellow stripes . . . . . *P. atra* Germar
1′. Forewings with 8 or more longitudinal veins, color brown with yellow mottling along veins . . . . . *P. pallescens* Germar

Genus *Scolops* Schaum

Scolops can be separated from other Illinois dictyopharids by the brownish forewings and slender, elongate frontal process. Four species occur in Illinois. The genus was reviewed by Breakey (1929) and Uhler (1900). The characters used in the following key are adapted from Breakey (1929).

Key to Species

1. Forewings with many crossveins in apical ⅓ — ¼ (Fig. 85) . . . . . *S. sulcipes* (Say)
1′. Forewings with few crossveins in apical ⅓ — ¼ (Figs. 86, 87) 2
2. Costal vein and cell white without fuscous markings . . . . . *S. angustatus* Uhler
2′. Costal vein and cell spotted with fuscous or gray 3
3. Forewings usually with fork on clavus and forks of media and cubitus nearly equidistant from each other (Fig. 86); aedeagus, in lateral view, with a heavily sclerotized ventral process; anal tube, in lateral view, with length of segment XI less than or equal to ⅔ length of anal style (Fig. 88) . . . . . *S. pungens* (Germar)
3′. Forewings usually with fork of cubitus closer to fork on clavus then to fork of media (Fig. 87); aedeagus, in lateral view, with a weakly sclerotized ventral process; anal tube, in lateral view, with length of segment XI subequal to length of anal style (Fig. 89) . . . . . *S. perdix* Uhler

Genus *Nersia* Stål

Nersia can be separated from other Illinois dictyopharids by the green body, clear forewings, and relatively short frontal process. *N. florens* Stål, which was included in Gibson's (1917) key as *Dictyophara florens,* is the only Illinois representative of the genus and occurs in the southern part of the state; it has been recorded from the southeastern and south central U. S. south to Central and South America (Metcalf 1946).

Genus *Rhynchomitra* Fennah

Rhynchomitra can be separated from other Illinois dictyopharids by the green body, clear forewings, and relatively long frontal process. *R. microrhina* (Walker), which was included in Gibson's (1917) key as *Dictyophara microrhina,* is the only Illinois representative of this genus and occurs in the southern part of the state; it has been recorded from the southeastern U. S. (Metcalf 1945).

Family Cixiidae Spinola

Most members of the family Cixiidae have no striking characteristics that easily distinguish them from other Illinois families, but can be separated from them by characters given in the key to families. This family is represented in Illinois by 7 genera and 22 species. The following key is adapted from Mead (1979).

Key to Genera

1. Antennae anterior to eyes and sunk in ear-like cavities . . . . . *Bothriocera*
1′. Antennae below eyes and not sunk in cavities 2
2. Forewings barely extending beyond apex of abdomen . . . . . *Monorachis*
2′. Forewings extending at least ¼ of their length beyond abdomen 3
3. Metatibiae with spines on lateral margin (Fig. 90) 4
3′. Metatibiae without spines on lateral margin 6
4. Wings strongly sloping downward laterally, almost vertical; forewings brown throughout and almost opaque . . . . . *Pintalia*
4′. Wings not strongly sloping downward laterally, roof-like or tent-like; forewings with some dark markings and usually translucent 5
5. Vertex with posterior margin angulate . . . . . *Oliarus*
5′. Vertex with posterior margin broadly rounded . . . . . *Cixius*
6. Vertex broadened posteriorly, width greater than ½ width of eye; pronotum with 3 longitudinal carinae . . . . . *Myndus*
6′. Vertex subparallel or narrowed posteriorly, width less than ½ width of eye; pronotum with 5 longitudinal carinae . . . . . *Oecleus*

Genus *Bothriocera* Burmeister

Bothriocera can be separated from other Illinois cixiids by the location of the antennae in ear-like cavities anterior to the eyes, and the superficial resemblance to psychodid flies. *B. signoreti* Stål, the only Illinois representative of this genus, occurs in the southern part of the state; it has been recorded from the southeastern U. S. (Metcalf 1936). The identification of Illinois specimens was based on external characters. However, the genitalia of these specimens do not resemble the illustrations given by Caldwell (1943). The genus appears in need of revision.

Genus *Monorachis* Uhler

Monorachis can be separated from other Illinois cixiids by the stout body and short forewings. *M. sordulentus* Uhler, the only species in the genus (Metcalf 1936), occurs in the southern part of Illinois; it has been recorded from the southeastern U. S. (Metcalf 1936). The only specimen from Illinois is deposited in the INHS collection.

Genus *Pintalia* Stål

Pintalia can be separated from other Illinois cixiids by the deeply sloping forewings, the superficial resemblance to derbids, and the spines on the lateral margin of the metatibiae which are relatively small and may be obscured by setae. *P. dorsovittatus* (Van Duzee), the only Illinois representative in the genus, occurs in the southern part of the state; it has been recorded from the southeastern U. S. (Metcalf 1936). The genus was reviewed by Caldwell (1944b) and Muir (1934) but appears in need of revision.

Genus *Oliarus* Stål

Oliarus can be separated from other Illinois cixiids by the angulate posterior margin of the vertex and generally hyaline, tent-like forewings. Seven species occur in Illinois. Since little distributional data are available, no attempt was made to include species of possible occurrence in Illinois. Thus, users of the key are cautioned to carefully compare the genitalia with the illustrations (Figs. 91-97). If there is any doubt as to the identify of a specimen, the descriptions and illustrations of Mead (1968) should be consulted. The genus was reviewed by Ball (1934), now outdated, and revised by Mead (1968). The following key was adapted from Mead (1968).

Key to Species

1. Forewings with apical ⅓ uniformly brown; aedeagus, in ventral view, with 1 median and 2 lateral spines (Fig. 91.) . . . . . *O. humilis* (Say)

1′. Forewings with apical ⅓ clear or with brown markings; aedeagus not as above (Figs. 92-97) 2

2. Aedeagus, in ventral view, with a single, large posteriorly directed process bearing many small spines (Fig. 92) . . . . . *O. quinquelineatus* (Say)

2′. Aedeagus, in ventral view, with several posteriorly directed processes, none bearing small spines (Figs. 93-97) 3

3. Aedeagus, in ventral view, with a loop curved to the left (Fig. 93) . . . . . *O. aridus* (Ball)

3′. Aedeagus, in ventral view, without a loop (Figs. 94-97) 4

4. Pygofer, in ventral view, with median process broadly expanded; aedeagus, in ventral view, with 2 large bifid processes (Fig. 94) . . . . . *O. placitus* Van Duzee

4′. Pygofer, in ventral view, with median process not broadly expanded; aedeagus, in ventral view, without 2 large bifid processes (Figs. 95-97) 5

5. Aedeagus, in ventral view, with a large bifid process at base of flagellum and a long dorsal sinuate spine on right (Fig. 95) . . . . . *O. ecologus* Caldwell

5′. Aeadeagus, in ventral view, without a large bifid process at base of flagellum and a long dorsal sinuate spine on right (Figs. 96, 97) 6

6. Aedeagus, in ventral view, with flagellum spinose apically (Fig. 96) . . . . . *O. sablensis* Caldwell

6′. Aedeagus, in ventral view, with flagellum subtriangular apically (Fig. 97) . . . . . *O. chuliotus* Ball

Genus *Cixius* Latreille

Cixius can be separated from other Illinois cixiids by the boadly rounded, posterior margin of the vertex and the generally hyaline, tent-like forewings. Four species occur in Illinois. Our identifications were based on comparisons of genitalia with the illustrations given by Osborn (1938). Color pattern characters, as in the keys of Beirne (1950a) and Metcalf (1923), are generally unreliable (Kramer, pers. comm.). The following key is adapted from Beirne (1950a). J. P. Kramer is currently revising the group (pers. comm.).

Key to Species

1. Vertex with length subequal to width, and triangularly shaped . . . . . *C. stigmata* (Say)
1′. Vertex with length much less than width, and not triangularly shaped 2
2. Forewings almost opaque, entirely brown . . . . . *C. pini* Fitch
2′. Forewings hyaline, often with brown markings 3
3. Forewings usually with a dark basal transverse band; length from head to apex >5.5 mm . . . . . *C. basalis* Van Duzee
3;. Forewings without a dark basal transverse band; length from head to apex <5 mm . . . . . *C. coloepeum* Fitch

Genus *Myndus* Stål

Myndus can be separated from other Illinois cixiids by the vertex which widens posteriorly, and by the lack of spines on the lateral margin of the metatibiae. Four species occur in Illinois. *M. ovatus* Ball has been recorded from Georgia, Iowa, Kansas, Maryland, Massachusetts, New Jersey and Virginia (Kramer 1979) and, thus, may occur in Illinois. The following key, adapted from Kramer (1979), separates 3 of the 5 species on the basis of characters of the aedeagus; however, the aedeagus of *M. pictifrons* Stål (Fig. 100) is quite variable (Kramer 1979). This genus was reviewed by Ball (1933), now outdated, and revised by Kramer (1979).

Key to Species

1. Frons with dark transverse bands 2
1′. Frons without dark transverse bands 4
2. Aedeagus, in lateral view, with a large dorsoposteriorly directed process (Fig. 98) . . . . . *M. truncatus* Metcalf
2′. Aedeagus, in lateral view, without a dorsoposteriorly directed process (Figs. 99, 100) 3
3. Aedeagus, in lateral view, with the ventroanteriorly directed process on left side spatulate or subtruncate (Fig. 99) . . . . . *M. radicis* Osborn (in part)
3′. Aedeagus, in lateral view, with the ventroanteriorly directed process on left side tapered, not spatulate (Fig. 100) . . . . . *M. pictifrons* Stål
4. Anal tube with large lobe on ventral margin in basal ½ . . . . . *M. ovatus* Ball
4′. Anal tube without lobe on ventral margin in basal ½ (Fig. 99) 5

5. Vertex broad, interocular space ca. as wide as eye or wider . . . . . *M. fulvus* Osborn

5′. Vertex narrow, interocular space much narrower than eye . . . . . *M. radicis* Osborn (in part)

Genus *Oecleus* Stal

Oecleus may be separated from other Illinois cixiids by the narrow vertex and small size. Four species occur in Illinois. The Illinois records of *O. chrisjohni* Kramer and *O. epetrion* Kramer are from Wilson and McPherson (1979b). The genus was reviewed by Ball and Klingenberg (1935) and Caldwell (1944c), and revised by Kramer (1977).

Key to Species

1. Pygofer with a narrow and spatulate median lobe; aedeagus, in ventral view, with 2 short processes on left (Fig. 101) . . . . . *O. chrisjohni* Kramer

1′. Pygofer with a broad and triangular or subtriangular median lobe; aedeagus not as above (Figs. 102-104) 2

2. Aedeagus, in ventral view, with 2 long slender processes on left (Fig. 102) . . . . . *O. borealis* Van Duzee

2′. Aedeagus, in ventral view, with 1 short process on left and 1 short median process (Figs. 103, 104) 3

3. Aedeagus, in ventral view, with left process needle-like (Fig. 103) . . . . . *O. epetrion* Kramer

3′. Aedeagus, in ventral view, with left process stout, not needle-like (Fig. 104) . . . . . *O. productus* Metcalf

Family Flatidae Spinola

The family Flatidae can be separated from other Illinois families by the presence of a row of many crossveins between the costal and subcostal veins, and by the granulate appearance of the clavus (Figs. 105, 106). It is represented in Illinois by 4 genera and 4 species. Keys to the flatid genera and species are given in Dozier (1928), Metcalf (1923), Osborn (1938) and Van Duzee (1923).

Key to Genera

1. Forewings, in lateral view, greatly narrowed posteriorly . . . . . *Cyarda*

1′. Forewings, in lateral view, subequal in width for most of their length or broader posteriorly 2

2. Body dark bluish gray or brown (may be obscured by white waxy powder) . . . . . *Metcalfa*

2′. Body bluish green or pale green (may be obscured by white waxy powder) 3

3. Forewings broadly rounded posteriorly and with 1 subapical crossvein (Fig. 105) . . . . . *Ormenoides*

3'. Forewings truncate posteriorly and with 2 subapical crossveins (Fig. 106) . . . . . *Anormenis*

Genus *Cyarda* Walker

Cyarda can be separated from other Illinois flatids by the forewings which are greatly narrowed posteriorly. *C. melichari* Van Duzee, the only Illinois representative of this genus, occurs in the southern part of the state; it has been recorded from the southeastern U. S. and West Indies (Metcalf 1957).

Genus *Metcalfa* Caldwell and Martorell

Metcalfa can be separated from other Illinois flatids by the forewings which are bluish gray to brown, and subequal in width for most of their length. *M. pruinosa* (Say), the only representative of this genus in America north of Mexico (Metcalf 1957), occurs throughout Illinois; it has been recorded from Quebec south to Florida, and west to Minnesota and California, as well as Bermuda, Cuba, Jamaica, Puerto Rico, Mexico, Central America and Brasil (Metcalf 1957).

Genus *Ormenoides* Melichar

Ormenoides can be separated from other Illinois flatids by the forewings which are bluish green to pale green, subequal in width, and have 1 subapical crossvein (Fig. 105). *O. venusta* (Melichar), the only Illinois representative of this genus, occurs in the southern part of the state; it has been recorded from Maryland south to Florida, and west to Missouri and Texas (Metcalf 1957).

Genus *Anormenis* Melichar

Anormenis can be separated from other Illinois flatids by the forewings which are bluish green to pale green, broaden posteriorly, and have 2 subapical crossveins (Fig. 106). *A. septentrionalis* (Spinola), the only Illinois representative of this genus, occurs throughout the state; it has been recorded from Connecticut south to Florida, and west to Iowa and Arizona (Metcalf 1957).

Family Acanaloniidae Amyot and Serville

The family Acanaloniidae can be separated from other Illinois families by the generally green body color, and the reticulate venation of the vertically held forewings. It is represented in Illinois by 1 genus, *Acanalonia,* and 2 species. Fennah (1954) included this family as a subfamily of Issidae. However, we have followed Metcalf (1954b) in treating the Acanaloniidae as a separate family.

Genus *Acanalonia* Spinola

Two species of *Acanalonia, A. bivittata* (Say) and *A. conica* (Say), occur in Illinois. *A. bivittata* has 2 color forms, 1 of which is green, the other, 'var. *rubra'* (Metcalf 1954b), which is reddish. Keys to species are given in Dozier (1928), Metcalf (1923) and Osborn (1938). The genus was reviewed by Doering (1932).

Key to Species

1. Forewings with hind margin broadly rounded; 2 dorsal longitudinal brown stripes extending from pronotum onto forewings; vertex slightly produced beyond eyes (Fig. 107) . . . . . *A. bivittata* (Say)

1'. Forewings with hind margin subtruncate; dorsal stripes lacking; vertex conical produced markedly beyond eyes (Fig. 108) . . . . . *A. conica* (Say)

Family Issidae Spinola

The family Issidae has no striking characteristics that easily distinguish it from other families, but can be recognized by those characters given in the key to families. It is represented in Illinois by 3 genera and 10 species. The subfamilies of the world were revised by Fennah (1954). The Issidae in America north of Mexico were reviewed by Doering (1936, 1938, 1940, 1941).

Key to Genera

1. Pronotum and mesonotum with many distinct circular pits; pronotum with a median carina 2
1′. Pronotum and mesonotum with, at most, a few obscure circular pits; pronotum without a median carina . . . . . *Thionia*
2. Frons, in lateral view, usually with margin sharply concave but if margin nearly straight, then pro- and mesotibiae flattened and expanded . . . . . *Fitchiella*
2′. Frons, in lateral view, with margin nearly straight or slightly convex; pro- and mesotibiae not flattened and expanded 3
3. Frons with 15 or fewer pits between lateral margin and each lateral carina 4
3′. Frons with 20 or more pits between lateral margin and each lateral carina . . . . . *Aphelonema* (in part)
4. Frons, in lateral view, sloping posteroventrally . . . . . *Aphelonema* (in part)
4′. Frons, in lateral view, sloping anteroventrally . . . . . *Bruchomorpha*

Genus *Thionia* Stål

Thionia can be separated from other Illinois issids by the lack of pits on the thorax, and the relatively large size and robust appearance. Three species occur in Illinois. The species in America north of Mexico were reviewed by Doering (1938).

Key to Species

1. Frons impunctate; body light brown with few or no dark markings . . . . . *T. simplex* (Germar)
1′. Frons punctate, at least along lateral margins; body medium to dark brown, heavily marked with dark brown to black 2
2. Frons with 1 carina (Fig. 109) . . . . . *T. elliptica* (Germar)
2′. Frons with 3 carinae (Fig. 110) . . . . . *T. bullata* (Say)

Genus *Fitchiella* Van Duzee

Fitchiella can be separated from other Illinois issids by the concave shape of the dorsal margin of the frons *(F. robertsonii* (Fitch)) or, if the margin is straight, by the flattened and expanded pro- and mesotibiae (Doering 1941). *F. robertsonii* was listed by Metcalf (1958) as occurring in Illinois.

However, no Illinois specimens were found in any of the collections examined and thus, the record is questionable. Keys to the species of *Fitchiella* were provided by Doering (1941) and Lawson (1933).

Genus *Aphelonema* Uhler

Aphelonema can be separated from other Illinois issids by the short frontal process and weevil-like appearance. Two species occur in Illinois. The species in America north of Mexico were reviewed by Bunn (1930) and Doering (1941).

Key to Species

1. Pronotum with median length subequal to that of vertex; forewings with black and yellow longitudinal dorsal stripes . . . . . *A. histrionica* (Stål)
1'. Pronotum with median length ca. 2 times that of vertex; body uniformly reddish brown . . . . . *A. simplex* Uhler

Genus *Bruchomorpha* Newman

Bruchomorpha can be separated from other Illinois issids by the generally elongate frontal process, the brownish to black body which may be marked with yellow, and the weevil-like appearance. Five species occur in Illinois. The species in America north of Mexico were reviewed by Ball (1935) and Doering (1940).

Key to Species

1. Frons, in dorsal view, with median length greater than length of eye; body black with a dorsal yellowish stripe that is usually restricted to head and thorax . . . . . *B. oculata* Newman
1'. Frons, in dorsal view, with median length less than length of eye; body black, brown or yellowish with length of dorsal stripe, if present, variable 2
2. Legs dark brown to black . . . . . *B. tristis* Stål
2'. Legs yellow, with or without brown markings 3
3. Body black with a dorsal yellow stripe that is restricted to head, or head and thorax . . . . . *B. pallidipes* Stål
3'. Body black, brown, or reddish brown, with a dorsal yellow stripe that extends from head onto abdomen, or body yellowish 4
4. Body black or brown with a dorsal yellow stripe that extends from head onto abdomen, often to apex . . . . . *B. dorsata* Fitch
4'. Body reddish brown or yellowish with a brown spot on clypeus; males with dark areas on forewings . . . . . *B. jocosa* Stål

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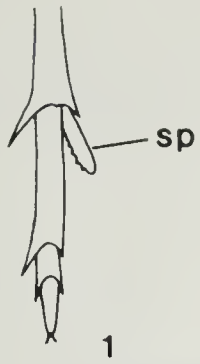
FIGURES

Figure

1. Generalized delphacid hind tibia and tarsus; sp = spur
2. Generalized achilid forewings
3. Frontal view of head of *Pentagramma vittatifrons*
4. Cross-section of first antennal segment of *Stobaera tricarinata*
5. Frontal view of head of *Stenocranus lautus*
6. Frontal view of head of *Peregrinus maidis*
7. Dorsal view of head and thorax of *Megamelus davisi*
8. Dorsal view of head and thorax of *Pissonotus brunneus;* m = m-shaped carina
9. Dorsal view of head and thorax of *Prokelisia crocea;* m = m-shaped carina
10. Dorsal view of head and thorax of *Kelisia curvata;* m = m-shaped carina
11. Dorsal view of head and prothorax of *Delphacodes campestris*
12. Dorsal view of head of *Liburniella ornata*



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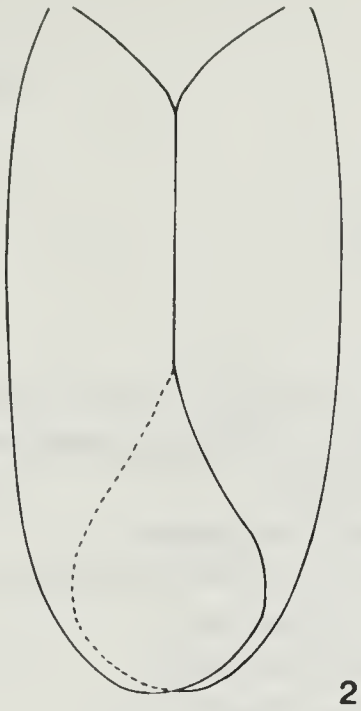

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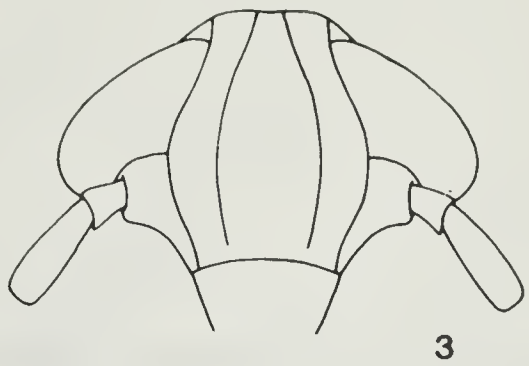

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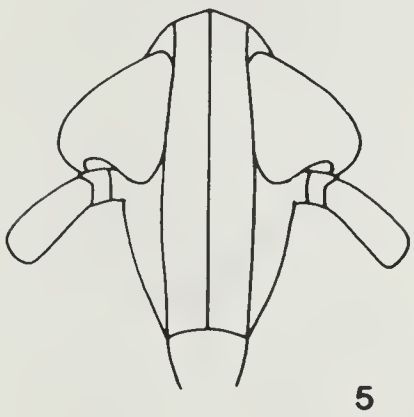

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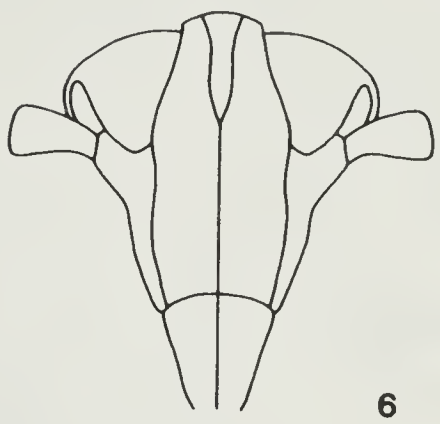

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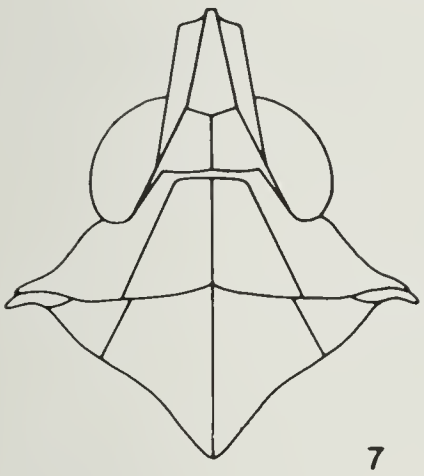

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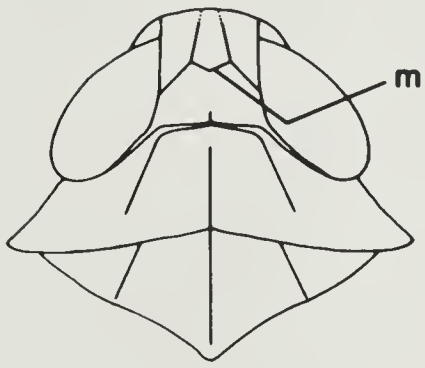

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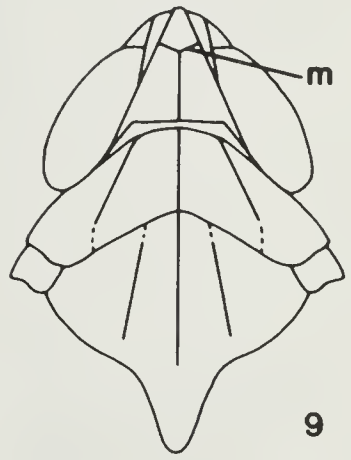

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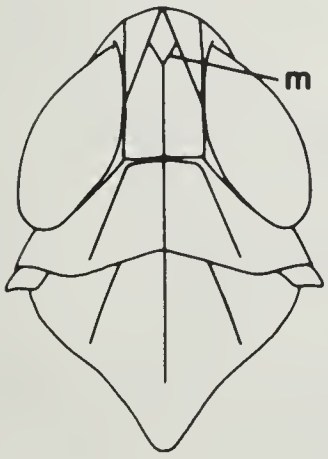

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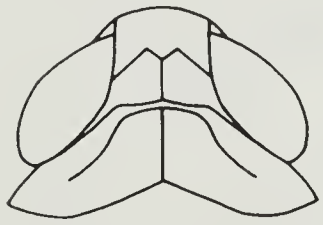

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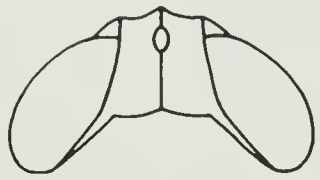

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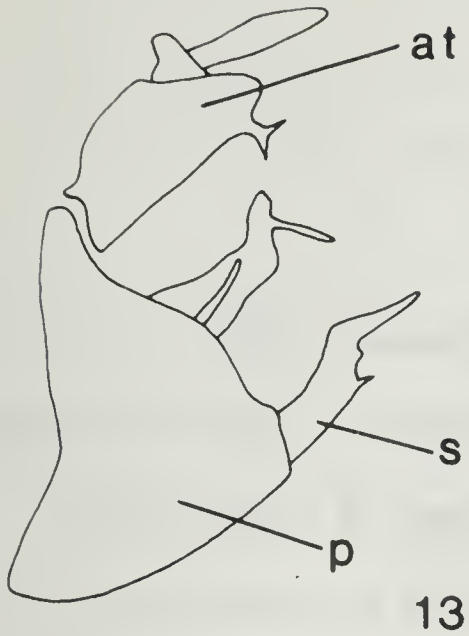
Figure

13. Lateral view of genitalia of *Stenocranus felti;* at = anal tube, p = pygofer, s = style
14. Genitalia of *Stenocranus pallidus*. A. Lateral view of genitalia; a = aedeagus, ap = aedeagal process. B. Ventral view of styles
15. Lateral view of genitalia of *Stenocranus sandersoni*
16. Genitalia of *Stenocranus similis*. A. Lateral view of genitalia. B. Ventral view of styles
17. Lateral view of genitalia of *Stenocranus delicatus*
18. Lateral view of genitalia of *Stenocranus brunneus*
19. Lateral view of genitalia of *Stenocranus unipunctatus*
20. Lateral view of genitalia of *Stenocranus lautus*



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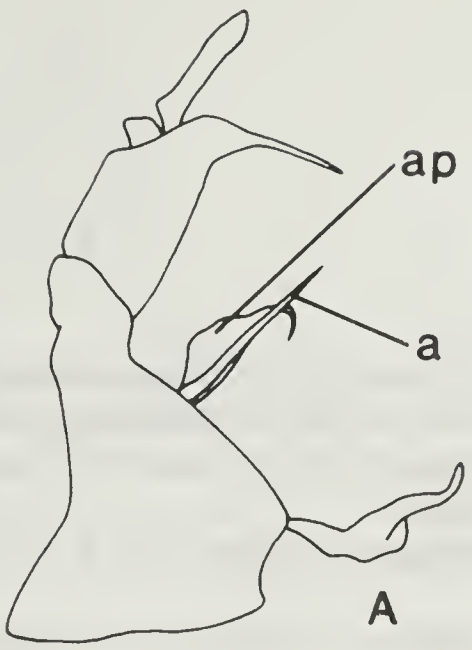

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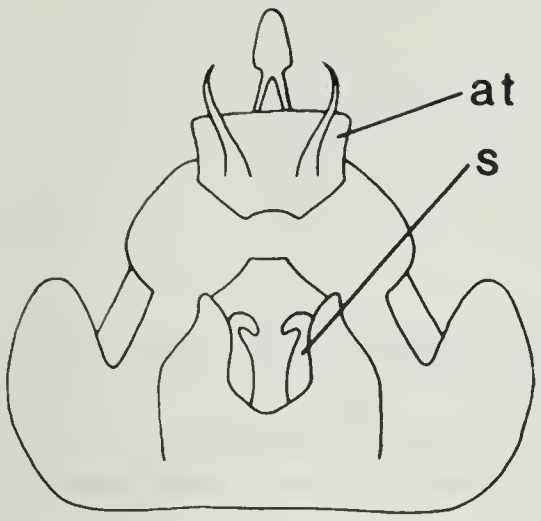
Figure

21. Caudal view of genitalia of *Megamelus davisi;* at = anal tube, s = style
22. Caudal view of genitalia of *Megamelus lunatus*
23. Genitalia of *Megamelus metzaria.* A. Caudal view of genitalia; p = pygofer. B. Lateral view of aedeagus
24. Genitalia of *Megamelus distinctus.* A. Caudal view of genitalia. B. Lateral view of aedeagus
25. Genitalia of *Megamelus palaetus.* A. Caudal view of genitalia. B. Lateral view of aedeagus
26. Caudal view of apex of aedeagus of *Pissonotus delicatus*
27. Lateral view of genitalia of *Kelisia spinosa;* ats = anal tube spine
28. Lateral view of genitalia of *Kelisia pectinata*
29. Lateral view of genitalia of *Kelisia curvata*



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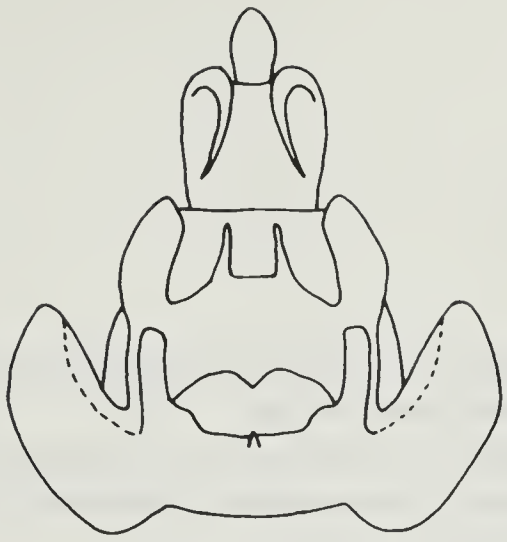

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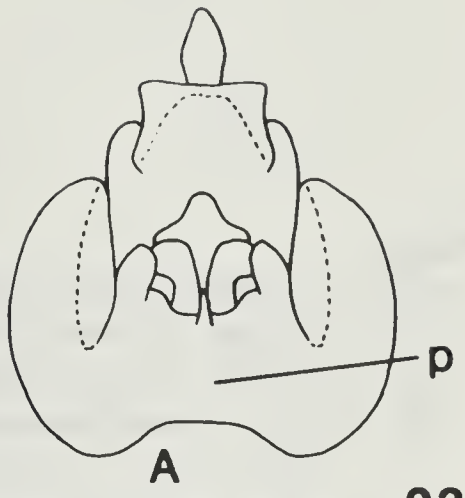

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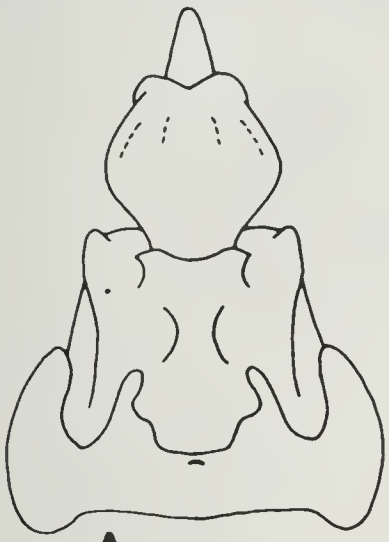

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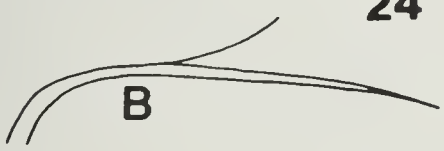

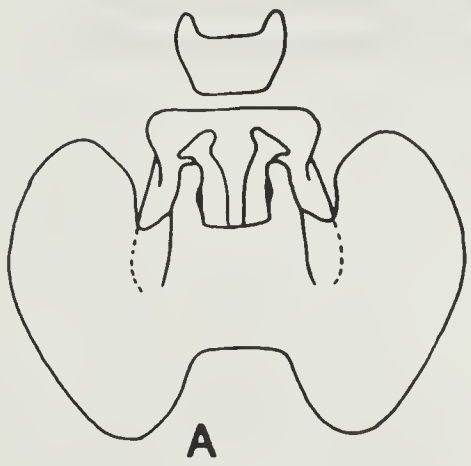

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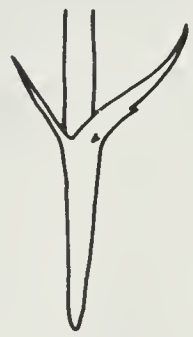

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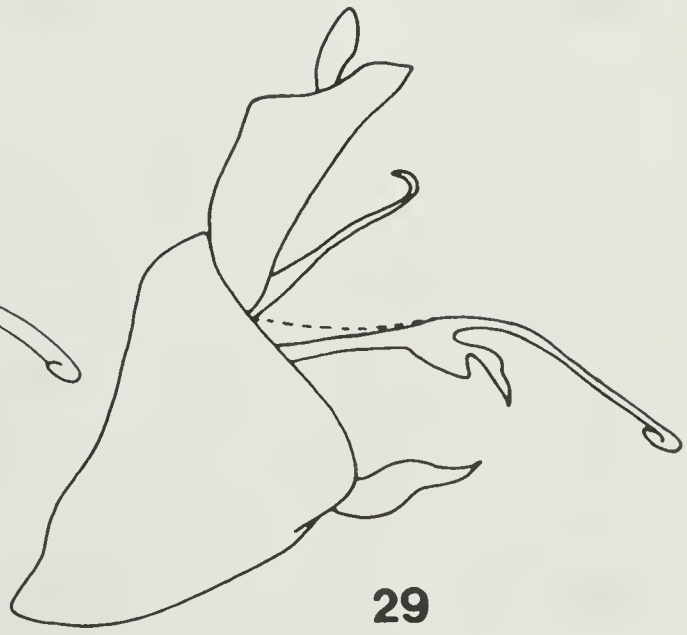

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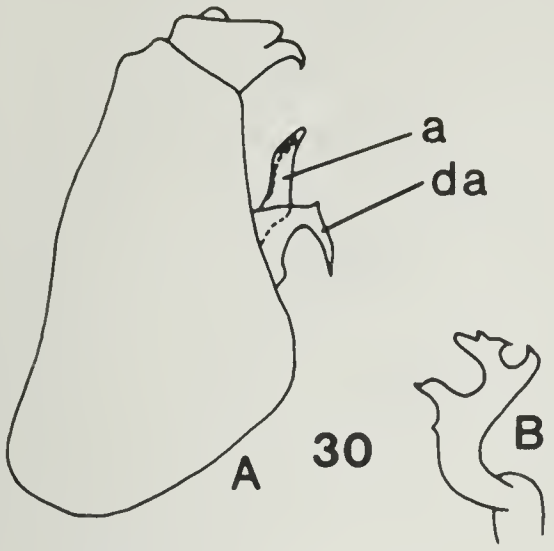
Figure

30. Genitalia of *Euides weedi*. A. Lateral view of genitalia; a = aedeagus, da = diaphragm armature. B. Ventral view of left style
31. Genitalia of *Euides gerhardi*. A. Lateral view of genitalia. B. Ventral view of left style
32. Lateral view of genitalia of *Delphacodes andromeda;* a = aedeagus, as = anal style, at = anal tube, p = pygofer, s = style
33. Genitalia of *Delphacodes basivitta.* A. Lateral view of genitalia. B. Ventral view of styles
34. Lateral view of genitalia of *Delphacodes analis*
35. Lateral view of genitalia of *Delphacodes atrata*
36. Lateral view of genitalia of *Delphacodes pellucida*
37. Lateral view of genitalia of *Delphacodes hyalina*
38. Lateral view of genitalia of *Delphacodes puella*
39. Lateral view of genitalia of *Delphacodes pacifica*



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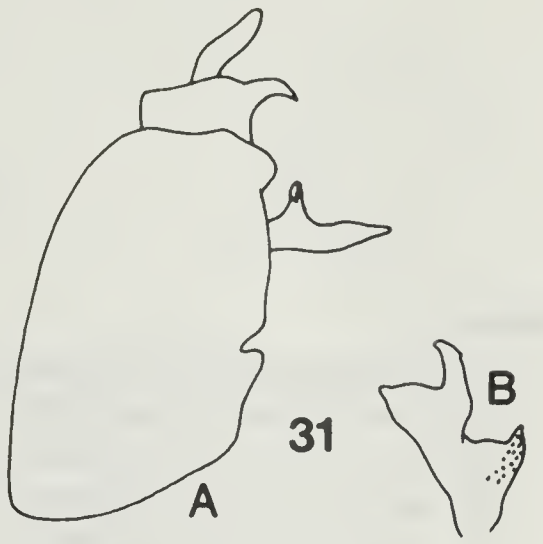

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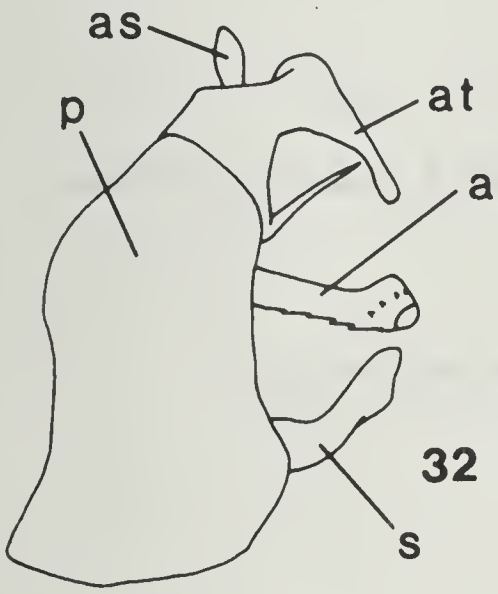

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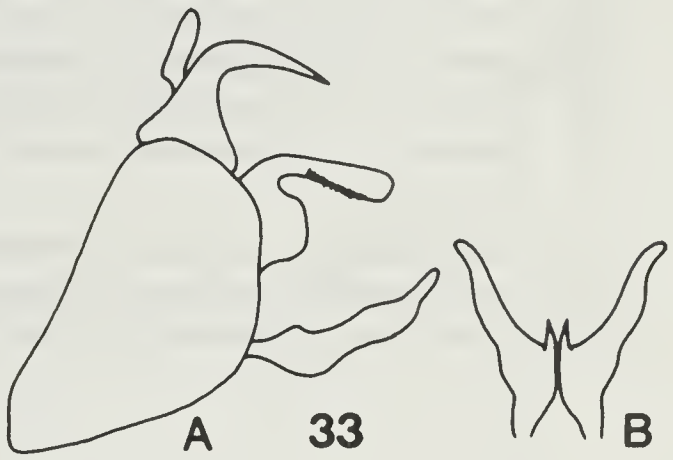

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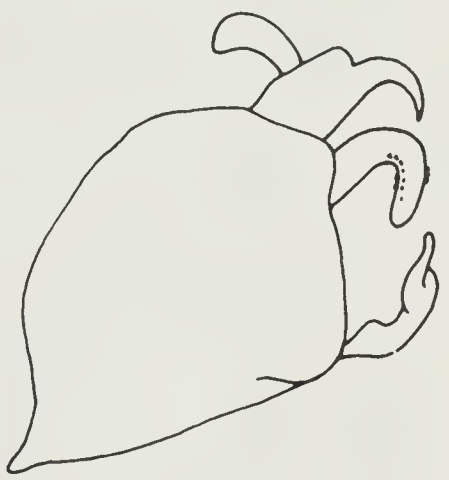

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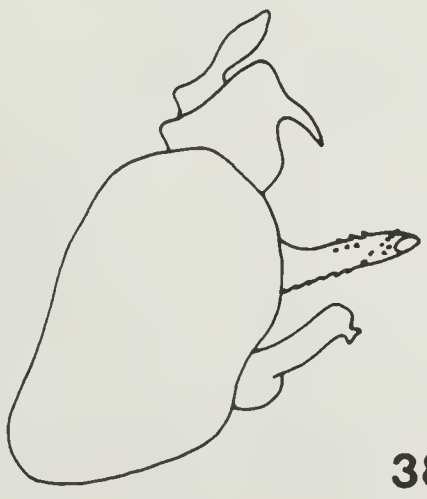

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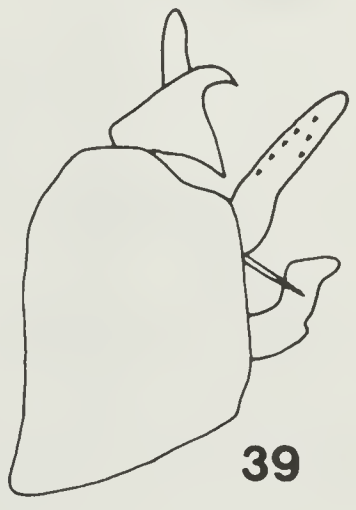

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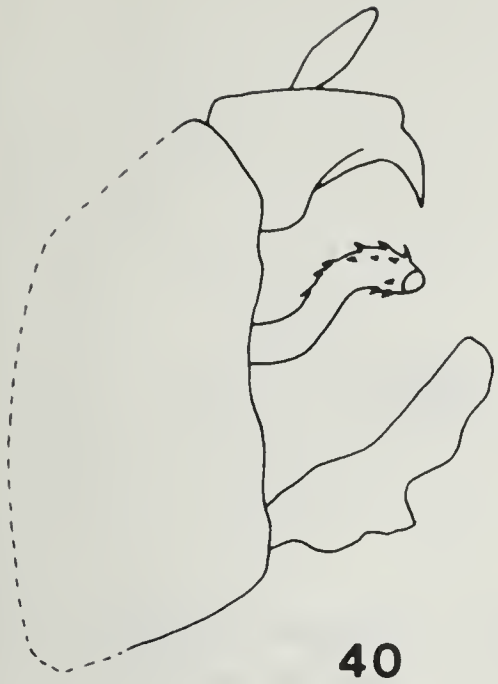
Figure

40. Lateral view of genitalia of *Delphacodes alexanderi*
41. Lateral view of genitalia of *Delphacodes mcateei*
42. Lateral view of genitalia of *Delphacodes nitens*
43. Lateral view of genitalia of *Delphacodes perusta*
44. Lateral view of genitalia of *Delphacodes dolera*
45. Lateral view of genitalia of *Delphacodes foveata*
46. Lateral view of genitalia of *Delphacodes propinqua*
47. Lateral view of genitalia of *Delphacodes laminalis*
48. Genitalia of *Delphacodes magna*. A. Lateral view of genitalia. B. Caudal view of anal tube.
49. Lateral view of genitalia of *Delphacodes campestris*
50. Lateral view of genitalia of *Delphacodes lutea*
51. Lateral view of genitalia of *Delphacodes parvula;* da = diaphragm armature



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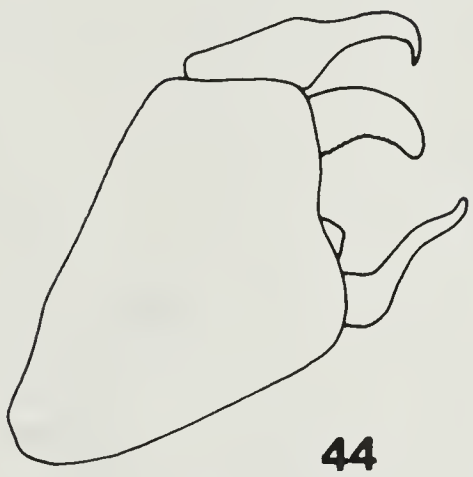

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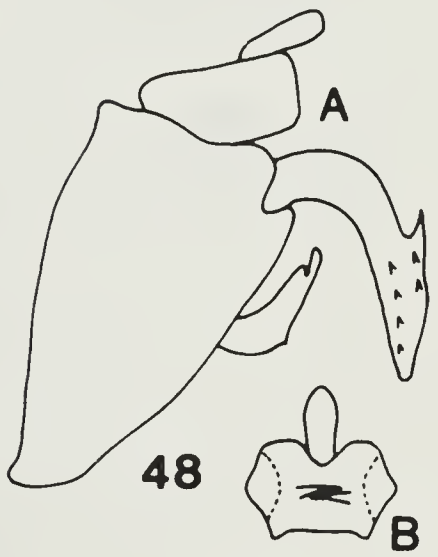

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Figure

52. Lateral view of genitalia of *Delphacodes rotundata;* da = diaphragm armature
53. Lateral view of genitalia of *Delphacodes lutulenta*
54. Lateral view of genitalia of *Chloriona slossoni*
55. Lateral view of genitalia of *Prokelisia crocea*
56. Lateral view of genitalia of *Prokelisoidea salina*
57. Dorsal view of head and prothorax of *Cyrpoptus belfragei;* ts = transverse sulcus
58. Dorsal view of head and prothorax of *Poblicia fuliginosa;* ts = transverse sulcus

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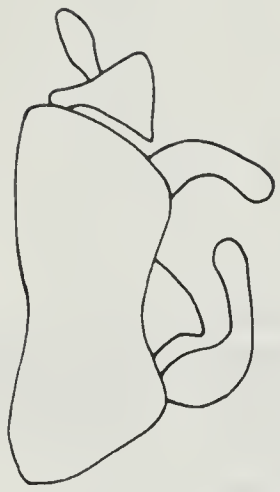

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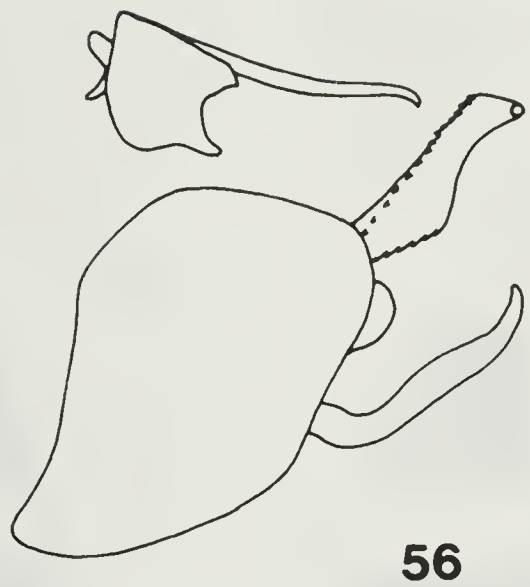

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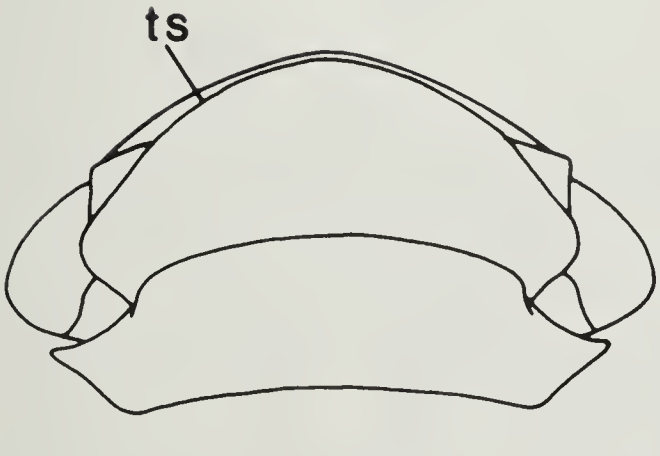

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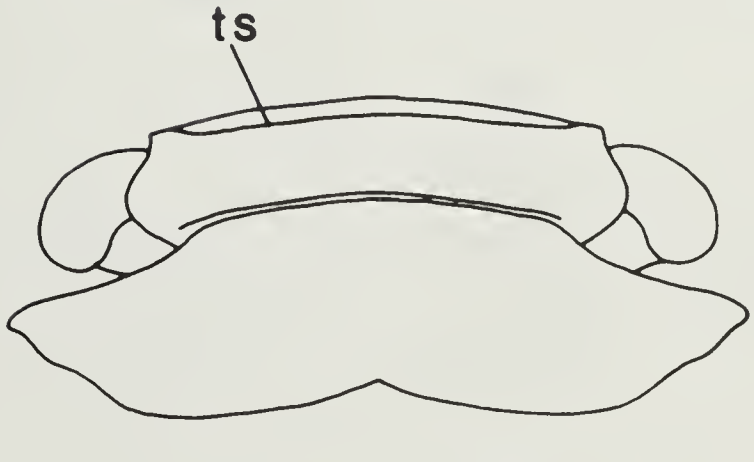

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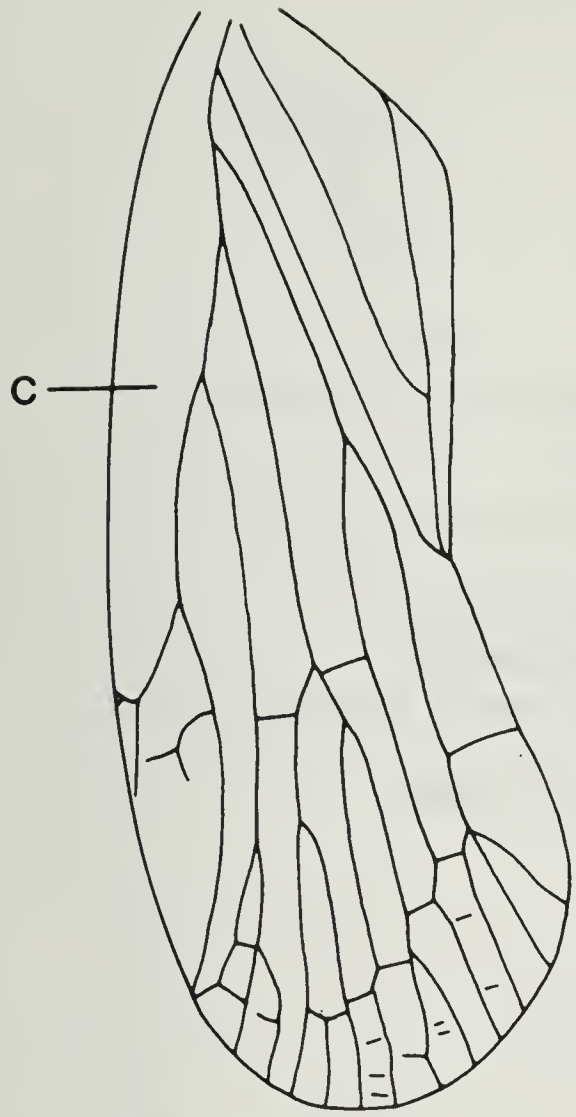
Figure

59. Forewing of *Epiptera opaca;* c = costal cell
60. Forewing of *Catonia nava;* c = costal cell, sc = subcostal cell
61. Forewing of *Synecdoche impunctata;* c = costal cell, sc = subcostal cell
62. Frontal view of head of *Catonia nava*
63. Frontal view of head of *Catonia bicinctura*
64. Frontal view of head of *Catonia cinctifrons*
65. Lateral view of genitalia of *Catonia pumila;* at = anal tube, p = pygofer, 1st = 1st pair of spines, 2nd = 2nd pair of spines, 3rd = 3rd pair of spines
66. Lateral view of aedeagus of *Catonia cinctifrons*
67. Lateral view of aedeagus of *Catonia carolina;* dl = dorsally extending lobe



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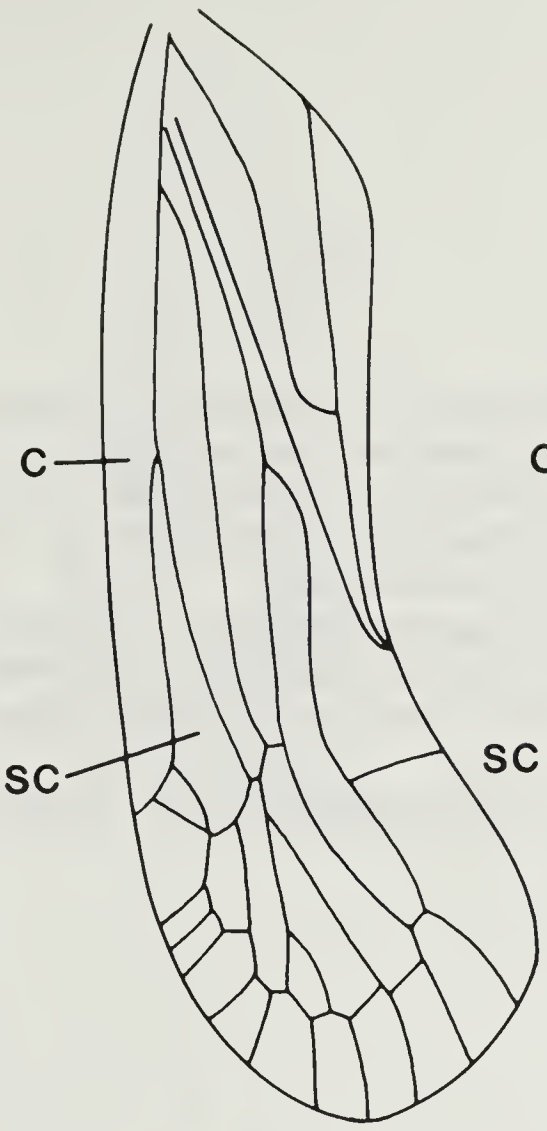

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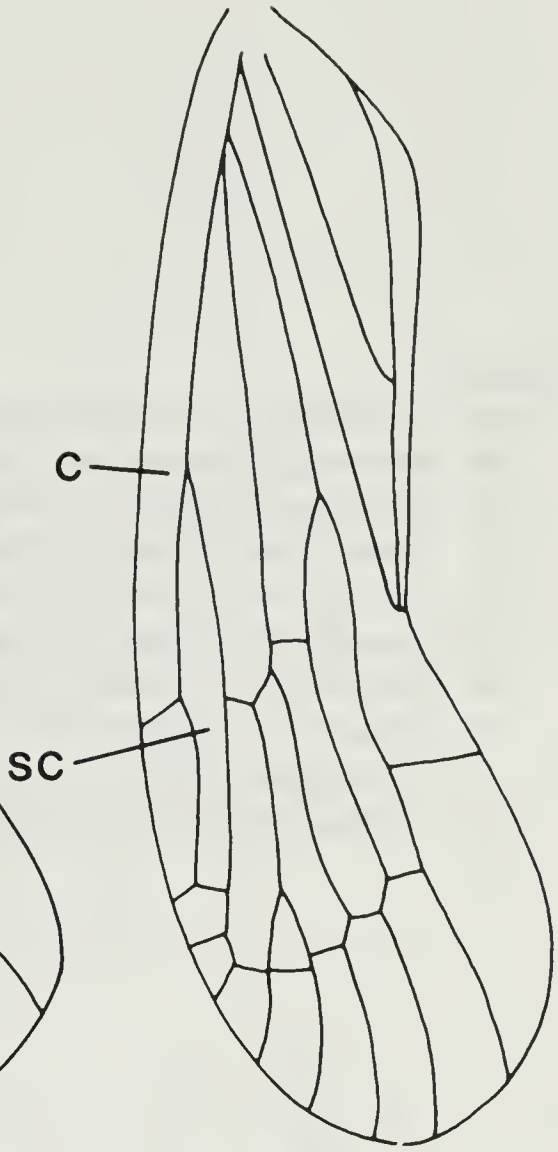

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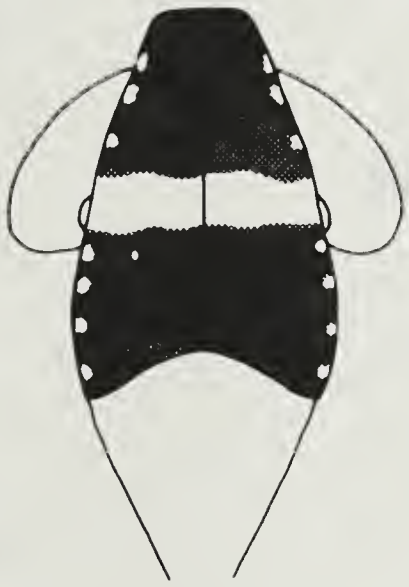

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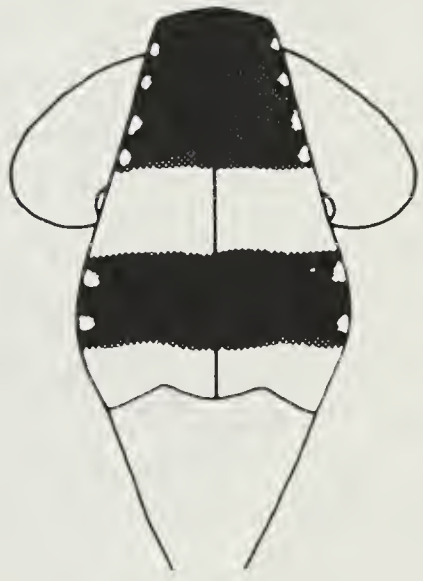

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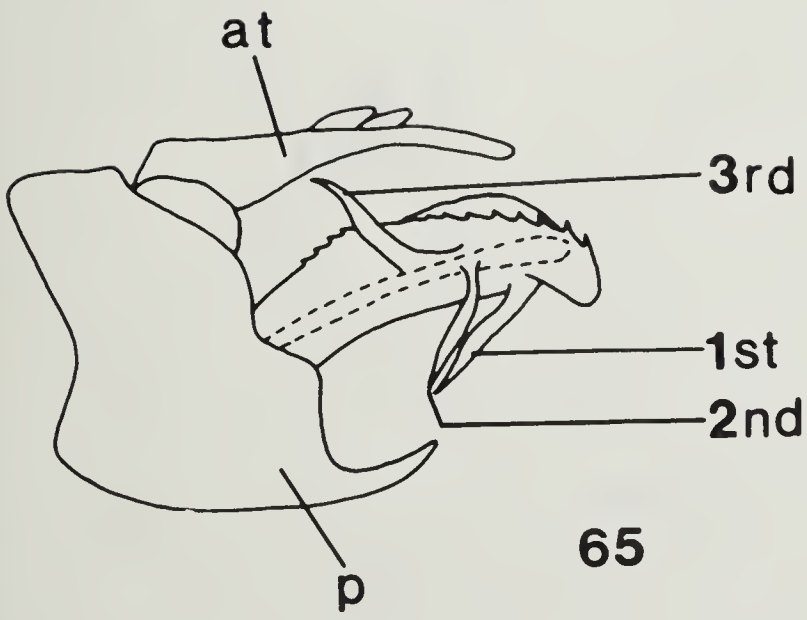

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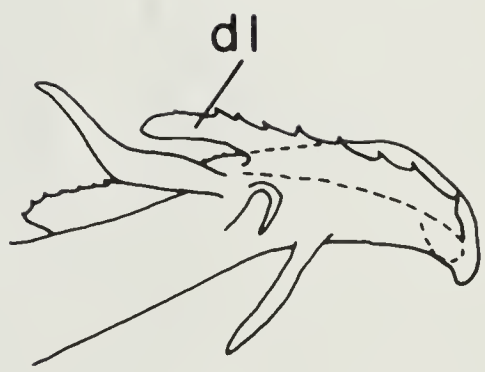
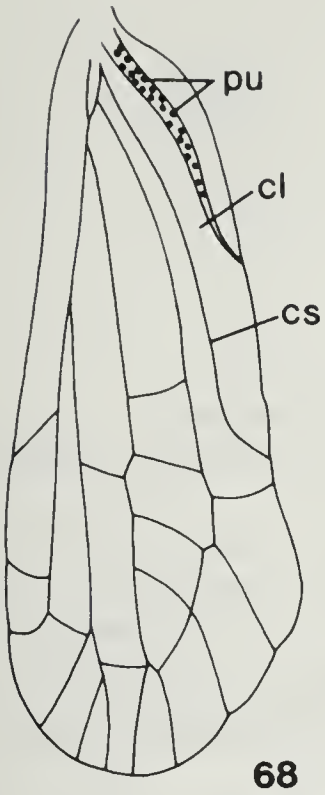


67

Figure

68. Forewing of *Patara vanduzei;* cl = clavus, cs = claval suture, pu = pustules
69. Forewing of *Amalopota uhleri;* cs = claval suture
70. Forewing of *Antotia burnetii;* cs = claval suture
71. Lateral view of head of *Shellenius schellenbergii;* aa = antennal appendage
72. Lateral view of head of *Shellenius ballii*
73. Lateral view of head of *Apache degeerii;* aa = antennal appendage
74. Lateral view of head of *Otiocerus wolfii;* aa = antennal appendage
75. Dorsal view of head, thorax and anterior portion of forewings of *Sayiana sayi;* ca = costal appendage
76. Frontal view of head of *Cedusa australis;* ex = extension of head



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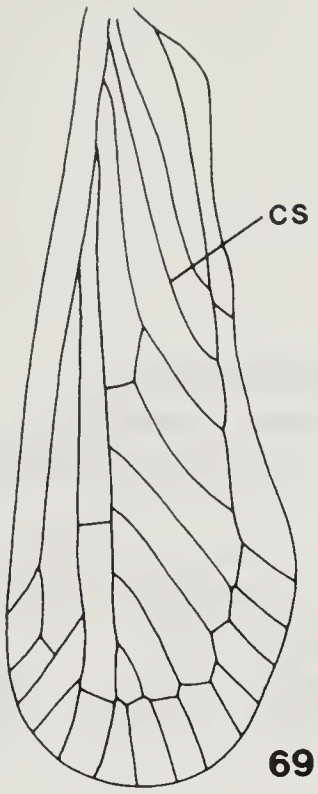

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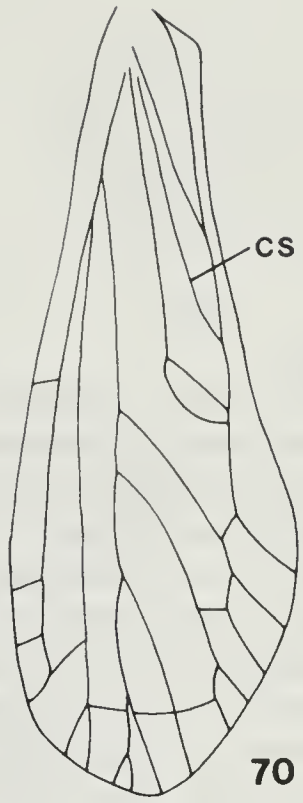

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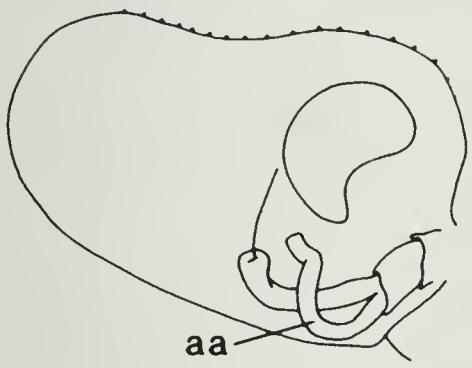

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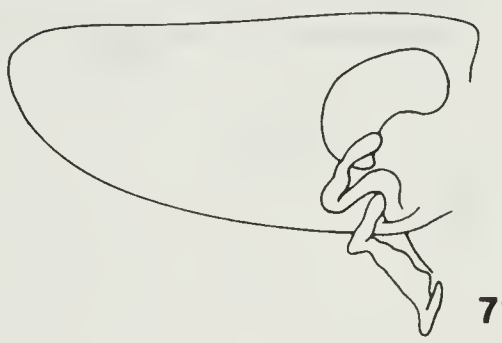

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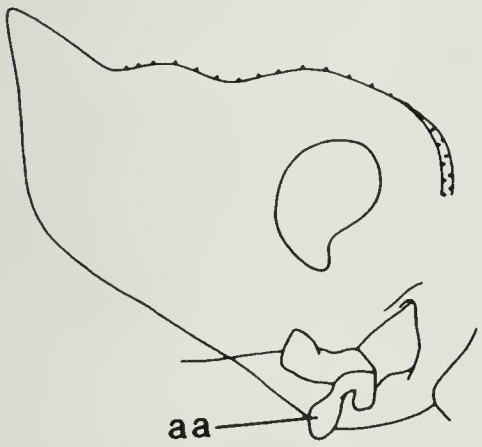

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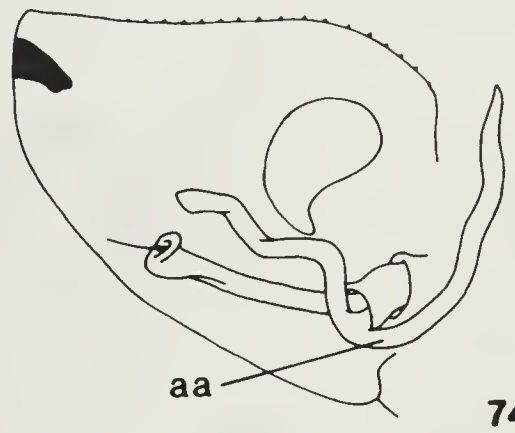

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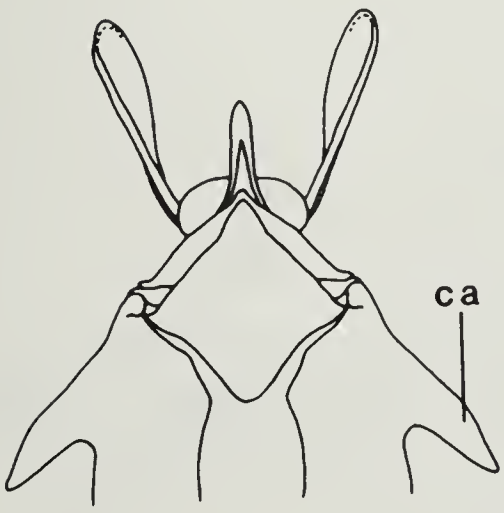

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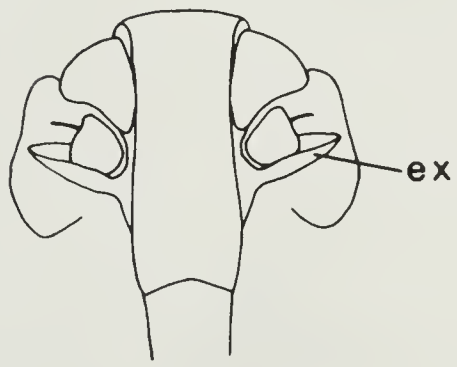
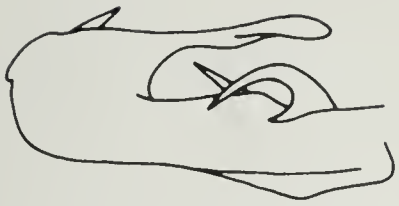


76

Figure

77. Lateral view of aedeagus of *Cedusa bedusa*
78. Lateral view of aedeagus of *Cedusa kedusa;* hp = horizontal process
79. Genitalia of *Cedusa incisa.* A. Lateral view of aedeagus; hp = horizontal process. B. Ventral view of right style
80. Genitalia of *Cedusa australis*. A. Lateral view of genitalia; at = anal tube, bp = bifid process, dp = dorsal process, f = flagellum of aedeagus, p = pygofer, sh = shaft of aedeagus. B. Ventral view of right style
81. Lateral view of genitalia of *Cedusa redusa;* bp = bifid process
82. Genitalia of *Cedusa edentula*. A. Lateral view of aedeagus; sl = scoop-like lobe. B. Ventral view of right style
83. Lateral view of aedeagus of *Cedusa vulgaris;* hp = horizontal process, spr = scroll-like process
84. Lateral view of aedeagus of *Cedusa obscura*



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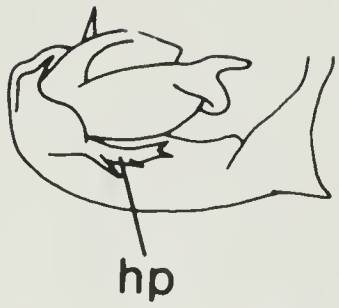

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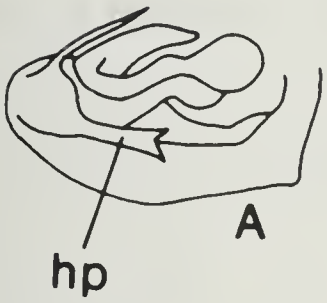

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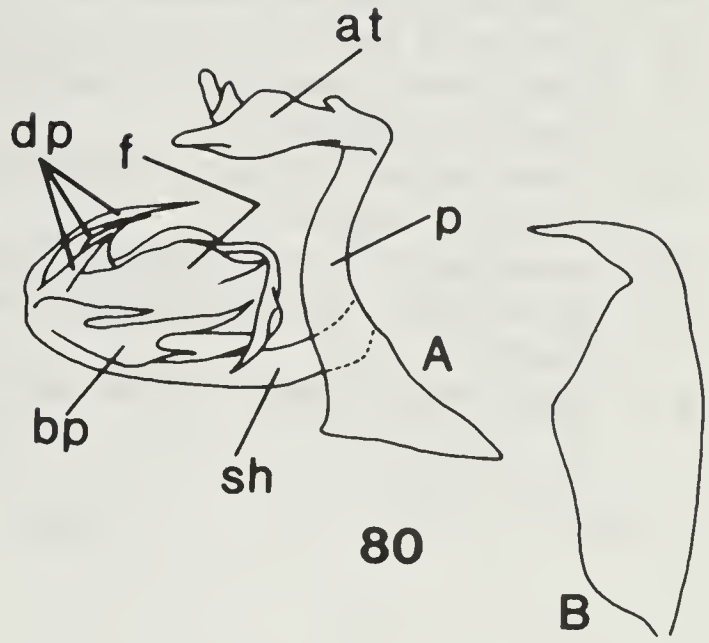

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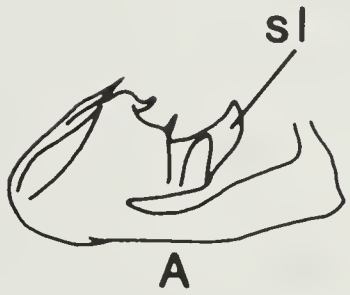

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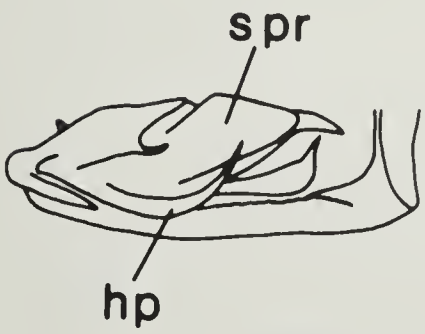

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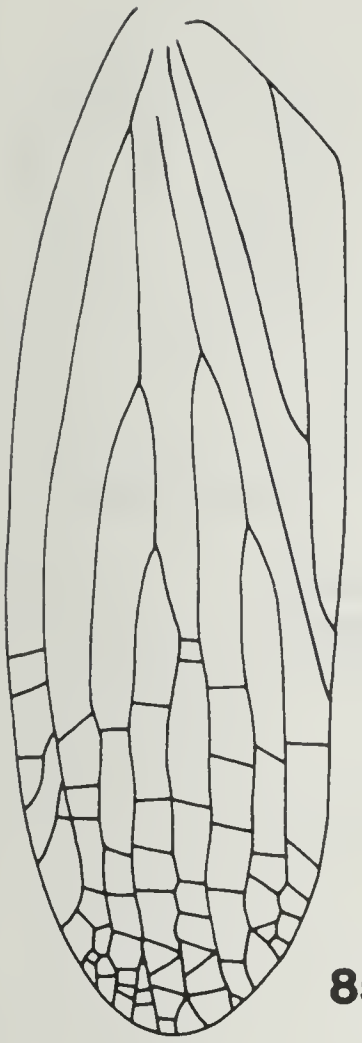
Figure

85. Forewing of *Scolops sulcipes*
86. Forewing of *Scolops pungens;* cu = cubitis, me = media
87. Forewing of *Scolops perdix;* cu = cubitus, me = media
88. Lateral view of anal tube and aedeagus of *Scolops pungens;* as = anal style, at = anal tube, XI = segment XI
89. Lateral view of anal tube and aedeagus of *Scolops perdix;* as = anal style, at = anal tube, XI = segment XI
90. Generalized cixiid hind tibia; tsp = tibial spines
91. Ventral view of genitalia of *Oliarus humilis;* ls = lateral spine, ms = median spine, p = pygofer
92. Ventral view of genitalia of *Oliarus quinquelineatus*



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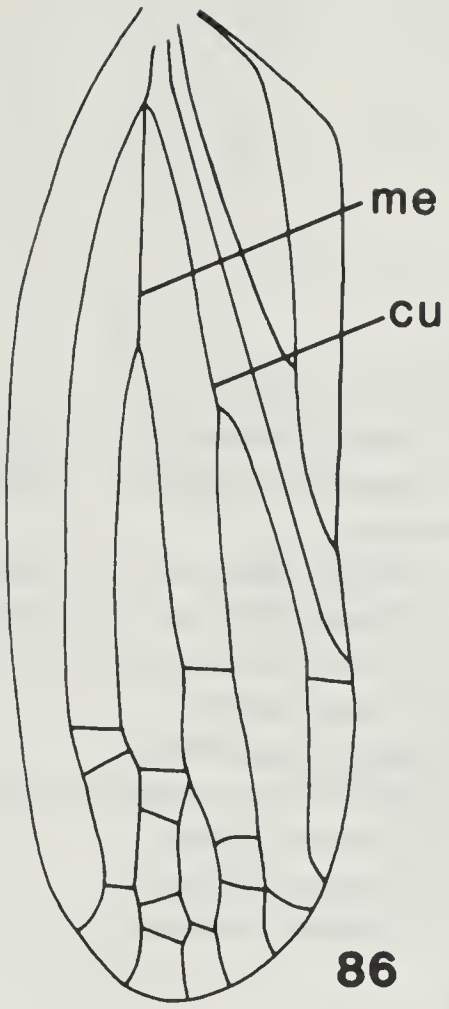

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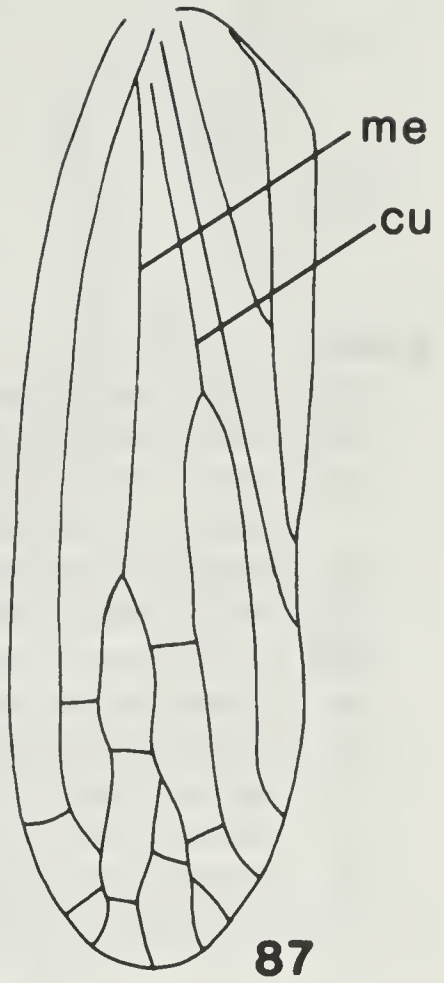

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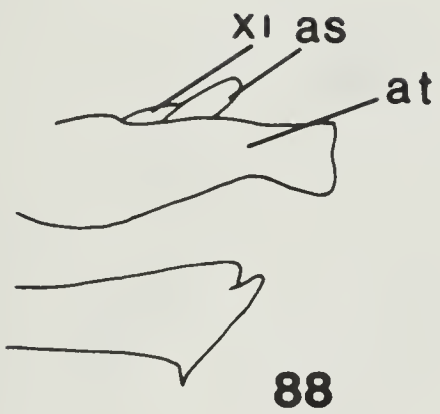

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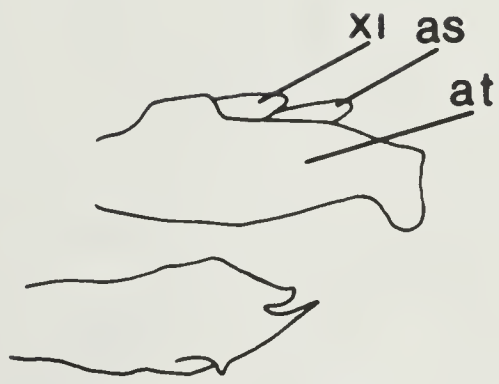

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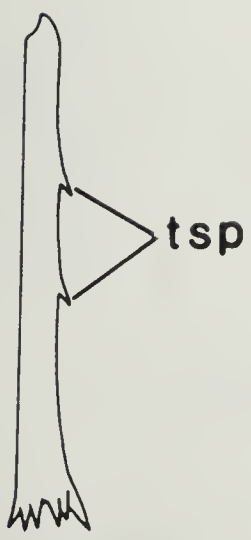

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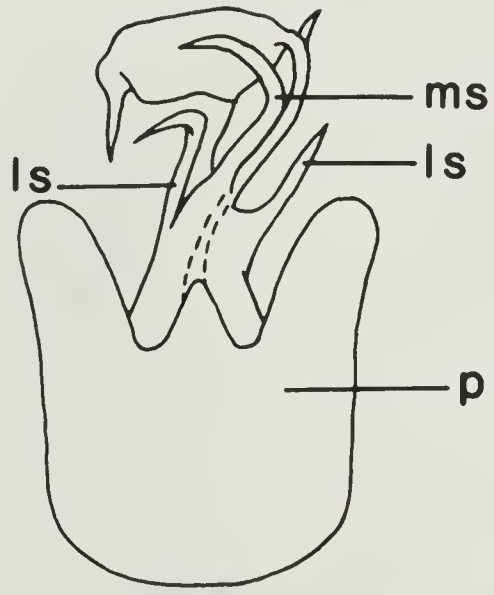

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Figure

93. Ventral view of genitalia of *Oliarus aridus*
94. Ventral view of genitalia of *Oliarus placitus;* bp = bifid process
95. Ventral view of genitalia of *Oliarus ecologus;* bp = bifid process, d = dorsal sinuate spine, f = flagellum of aedeagus
96. Ventral view of genitalia of *Oliarus sablensis;* f = flagellum of aedeagus
97. Ventral view of genitalia of *Oliarus chuliotus;* f = flagellum of aedeagus
98. Lateral view of genitalia of *Myndus truncatus*
99. Lateral view of genitalia of *Myndus radicis*
100. Lateral view of genitalia of *Myndus pictifrons*
101. Ventral view of genitalia of *Oecleus chrisjohni;* p = pygofer
102. Ventral view of genitalia of *Oecleus borealis*
103. Ventral view of genitalia of *Oecleus epetrion*
104. Ventral view of genitalia of *Oecleus productus*

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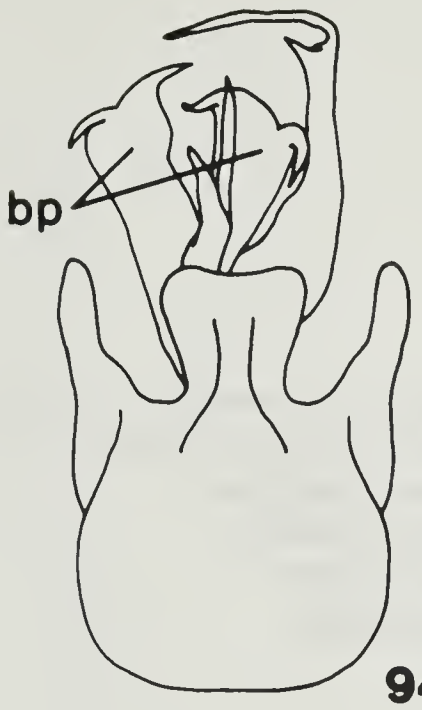

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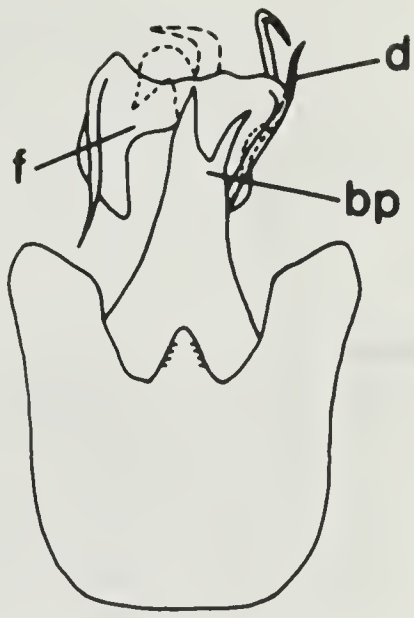

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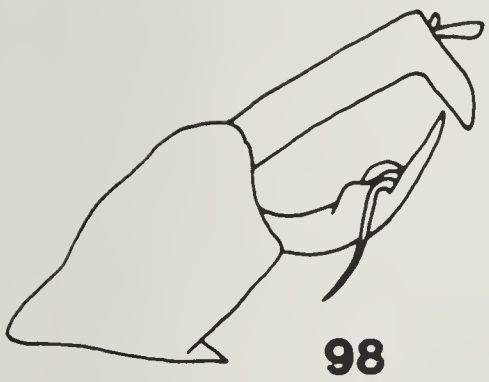

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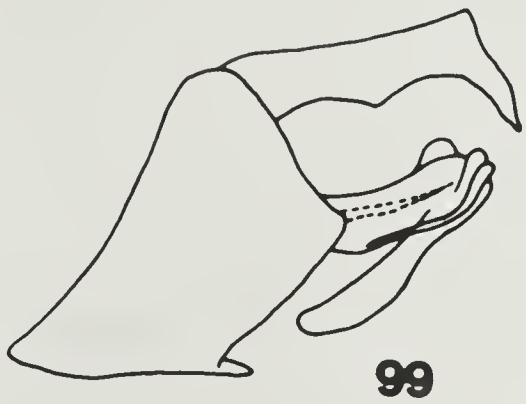

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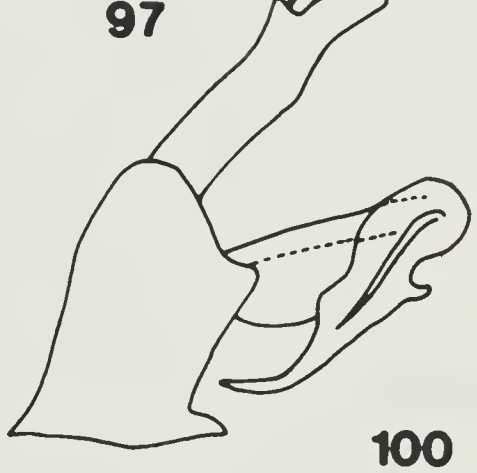

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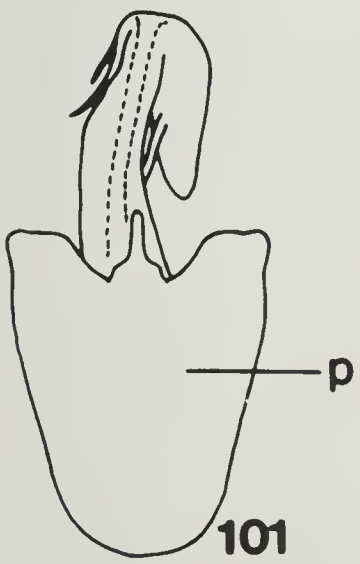

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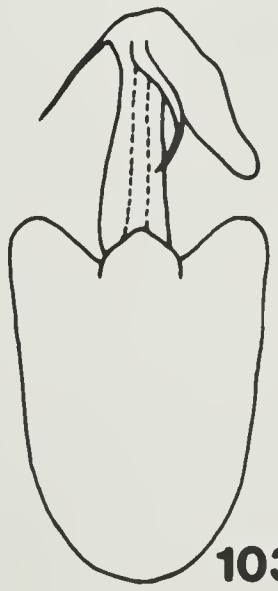

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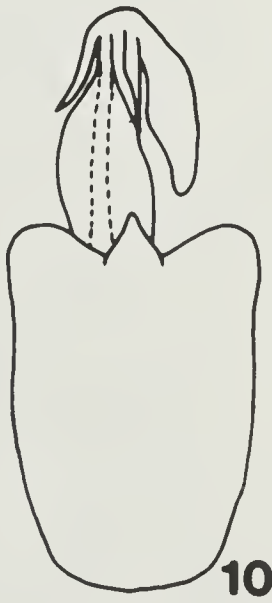

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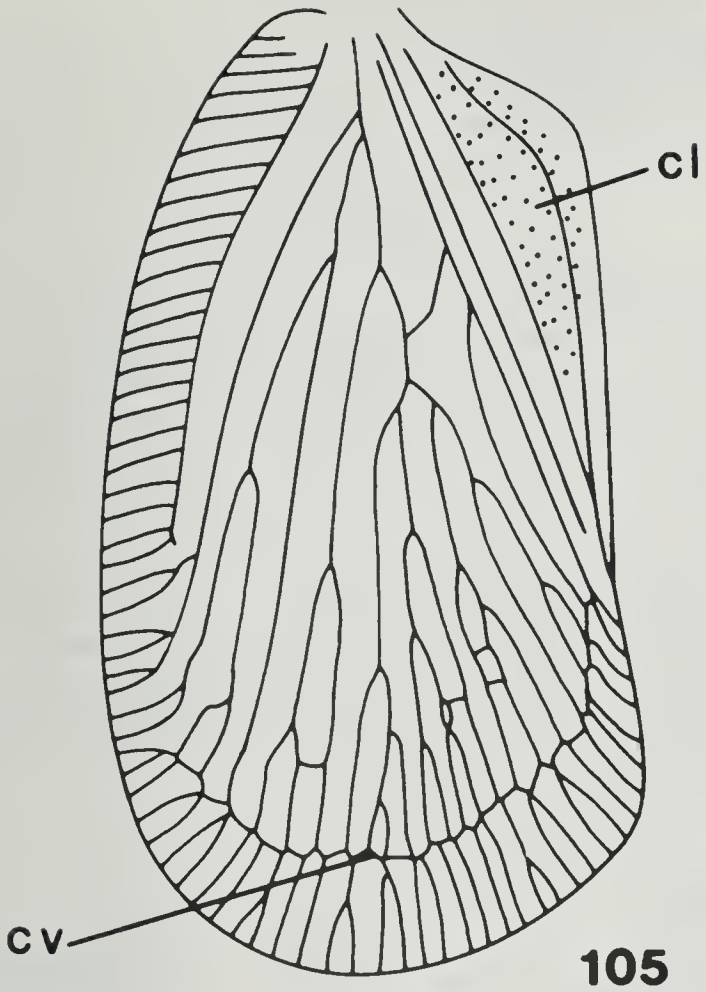
Figure

105. Forewing of *Ormenoides venusta;* cl = clavus, cv = subapical crossvein
106. Forewing of *Anormenis septentrionalis;* cl = clavus, cv = subapical crossvein
107. Lateral veiw of head of *Acanalonia bivittata*
108. Lateral view of head of *Acanalonia conica*
109. Frontal view of head of *Thionia elliptica*
110. Frontal view of head of *Thionia bullata*



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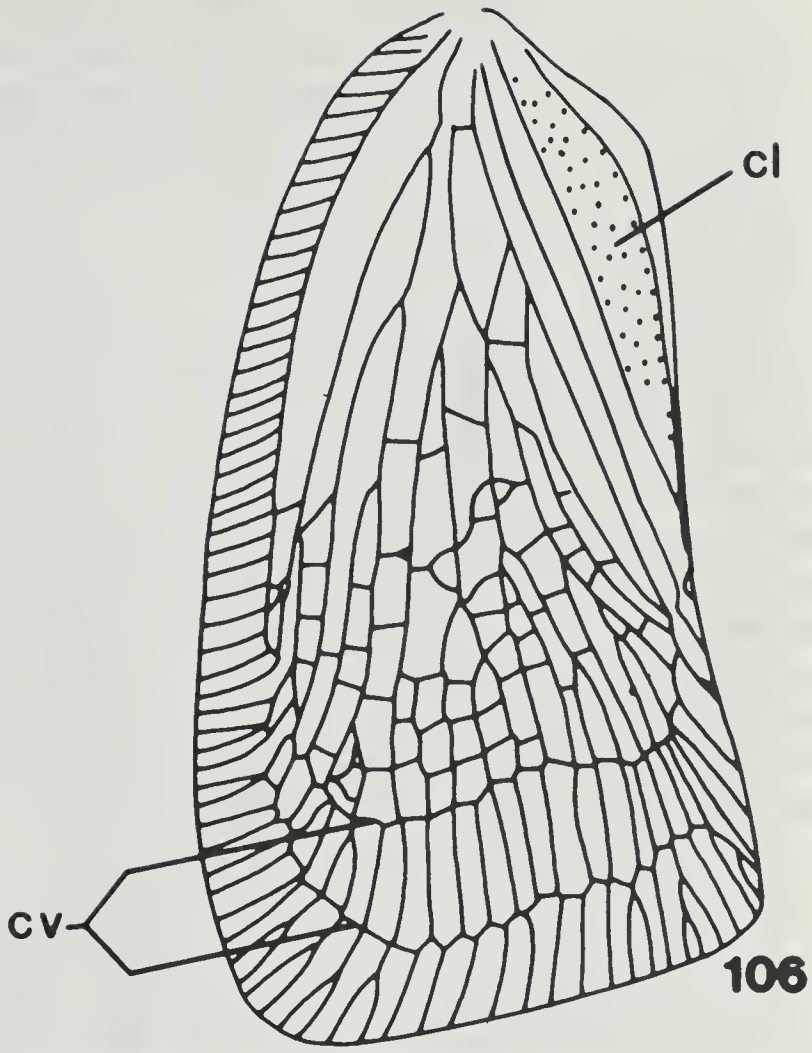

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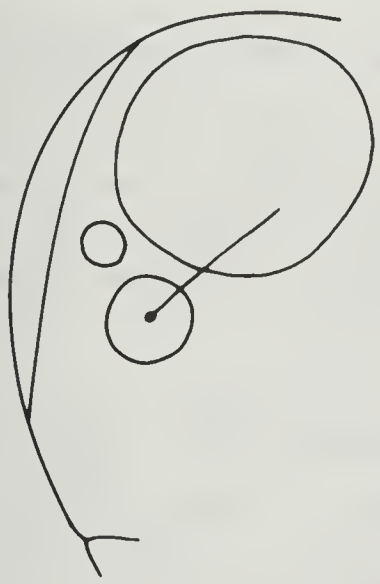

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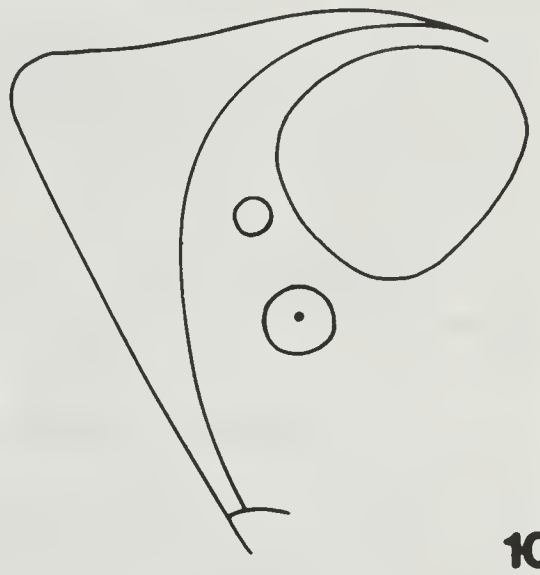

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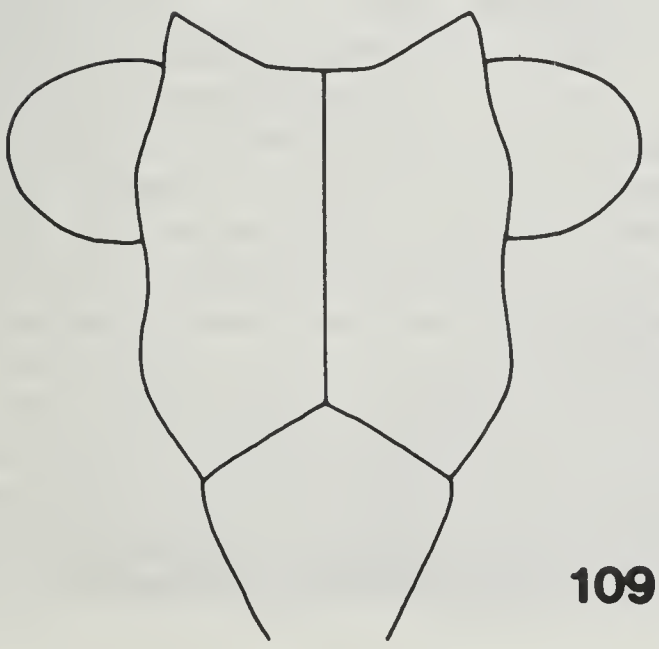

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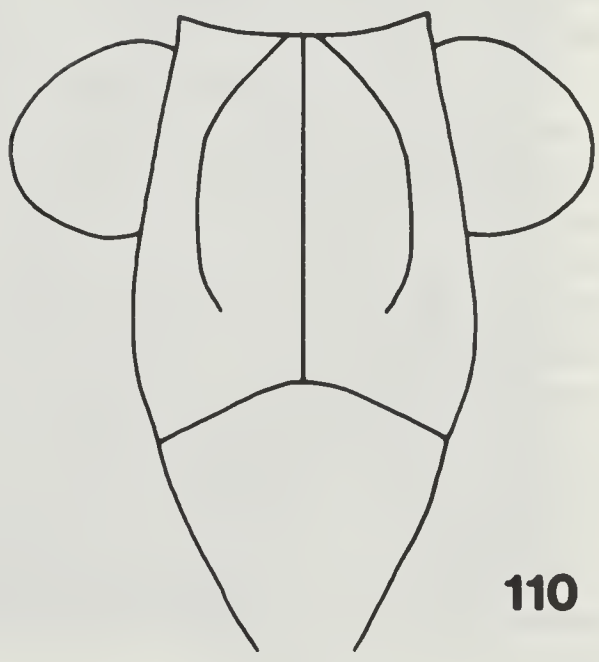


110

SIPAPU AND PYRAMID TOO: THE TEMPLE OF THE CRYPT AT ALTA VISTA, CHALCHIHUITES

Ellen Abbott Kelley and J. Charles Kelley
Sul Ross State University, Alpine, Texas

ABSTRACT

The Temple of the Crypt at Alta Vista was originally a free-standing tomb of a high status individual. Later, coinciding with the burial of a second high status individual, it was incorporated into the basal platform of a two-story temple built around and over it. Subsequently, the crypt was opened and a third high status individual was buried therein. The temple itself was an elevated rectangular room entered from the Southwest Court by an exterior stairway. The basement room containing the crypt must have been reached through a hatchway in the temple floor. The analogy to an above-ground rectangular kiva with a sipapu in the floor used as a god-entry is obvious. Later, superimposed constructions slowly converted the structure into a taluded Mesoamerican pyramid, topped by its own temple. This development suggests that some southwestern kiva-sipapu complexes are analagous to some Mesoamerican pyramid-tomb complexes and that both complexes have a common Mesoamerican origin.

INTRODUCTION

In a paper, "Sipapu and Plaza Too," delivered at the Reno, Nevada meeting of the Society for American Archaeology in 1966 (Kelley 1966 MS), J. Charles Kelley pointed out the occurrence of both plaza and kiva sipapus of the Southwestern Puebloan-Anasazi in ethnographic Huichol culture and archaeologically in sites of the Chalchihuites culture of Zacatecas and Durango, Mexico.

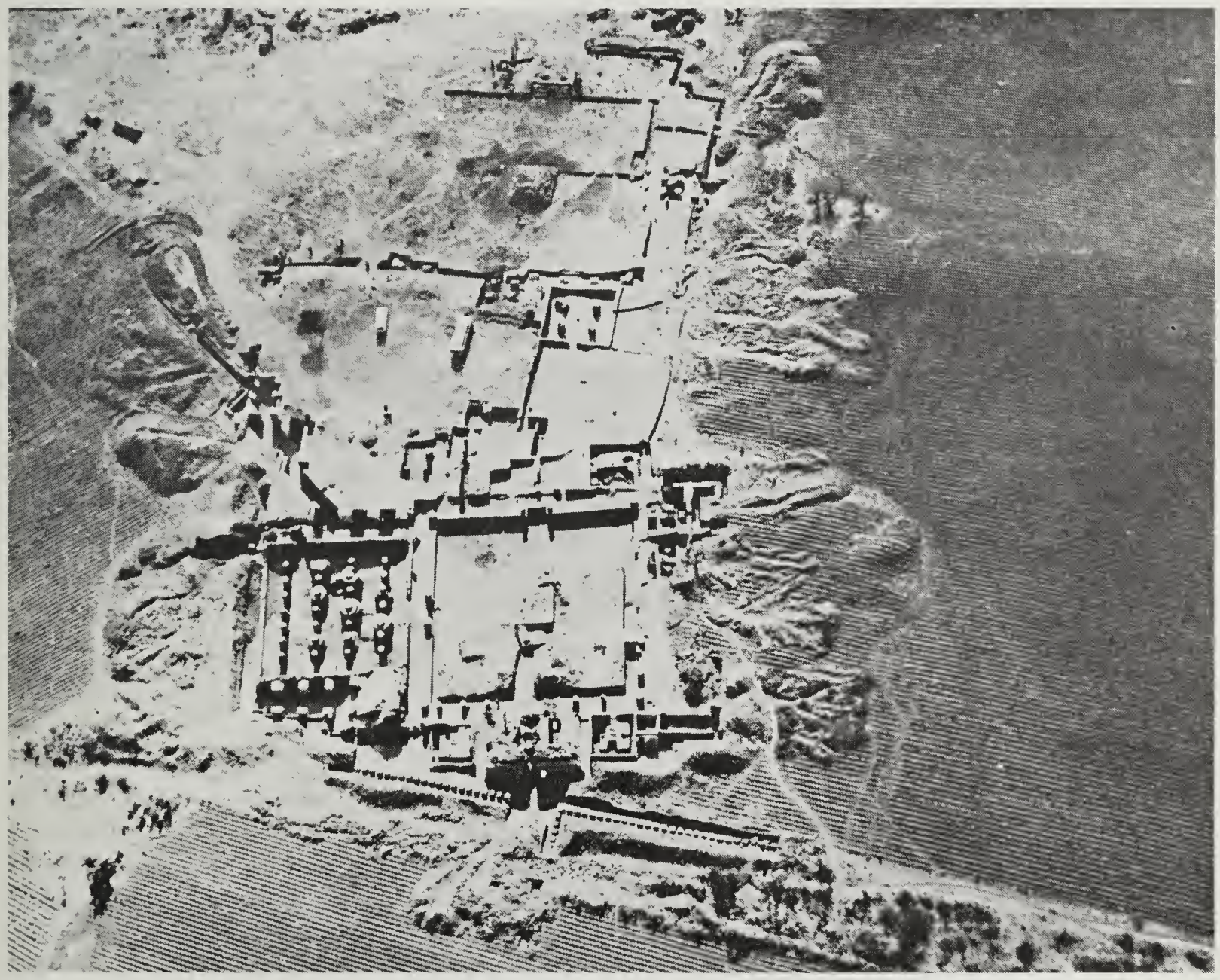
In our 1975-76 excavations at Alta Vista, Chalchihuites (Figure 1), in western Zacatecas, Mexico (financed by the Southern Illinois University at Carbondale and by the National Science Foundation under Grant SOC74-03759 AO2 we discovered, beneath a later pyramid, an early rectangular stone masonry building (the Temple of the Crypt), containing a basement area in which there was a subterranean burial crypt where three high status individuals had been buried sequentially. This find yielded a new understanding of the meanings and origin of the sipapu/kiva complex and its relation to Mesoamerican beliefs and practices.

THE NUCLEAR CONSTRUCTION CORE OF ALTA VISTA

Alta Vista (a Mexican National Monument) is the principal ceremonial center of the Chalchihuites culture, located near the town of Chalchihuites in western Zacatecas (Kelley 1971, 1976; Kelley and Kelley 1966). It was built as a planned and surveyed center, hypothetically by outside trader/missionaries from western Mexico as an extension of the Teotihuacan commercial and religious empire (Kelley 1974, 1976, 1977; Kelley and Kelley 1978).

The center and oldest section of the Alta Vista site (Figure 2) consists of a Hall of Columns (measuring approximately 20 by 20 meters), built on a taluded stone masonry platform, and a large forecourt (approximately 27 by 28 meters), the Southwest Court, surrounded by a raised banquette or walkway, to which were attached various platforms and structures. The principal structures were oriented with their corners toward the cardinal directions, rather than their wall lines. Survey stakes had been placed marking wall alignments, doors, column locations, and other architectural features, prior to the construction of the Hall of Columns and related structures, demonstrating that the ceremonial center was built according to a preconceived plan. Midway of the northwestern side of the Southwest Court, a cluster of three related structures formed a three-temple complex consisting of a central taluded pyramid and associated temples on each side (Figure 3A). The pyramid, Structure No. 2B, was reached from the Southwest Court by a balustraded stirway and evidently had been built in several stages. Its exterior walls and the stairway were cleared of debris during our 1974 excavations and the subterranean room was discovered near the end of the field session.

A



B

EXCAVATIONS IN STRUCTURES NO. 2B - THE SUN PYRAMID

In the last days of our 1975-76 season, excavation of the pyramid took place from above, exposing and largely clearing a subterranean room; through an erosional break on the northwest, exposing a cross-section of the pyramid construction and giving us access to the subterranean chamber; and from the southeast, where a trench along the exterior of the southwestern balustrade and stair demonstrated that the subterranean room was the interior of an early rectangular stone masonry room, the Temple of the Crypt, lying within and below the pyramid itself (Figure 4A). The latter trench also yielded much data regarding constructional stages. When the interior of the early structure was partially cleared, we discovered a covered burial crypt in its northwestern end (Figure 4B). There was evidence that the temple itself had been surveyed and constructed subsequent to the construction of the crypt, but because of insufficient available time, we were able to clear only the upper part of the exterior walls of the ''sarcophagus''; hence we have no firm excavational data regarding its exterior appearance. This crypt appeared to have originally been a free-standing ''sarcophagus'' or coffin of adobe and stone, erected on a ''use-floor'' just northwest of the point where a stairway from the Southwest Court reached the midpoint of the banquette on that side. Later, we discovered that a screen of three free-standing figures had been built on the outer edge of the banquette there, to be incorporated later into the stairway of the Temple (Figure 4A). Although ''sarcophagus' had clearly been built before the enclosing structure, the archaeological data gave us no indication of the length of the interval between the two constructional events.

The bathtub-like crypt had originally been left unfilled, except for its first burial, and had been covered with a roof of small poles laid side by side and covered with adobe. The bones of the first burial were somewhat scattered, perhaps representing a loosely-flexed inhumation, with the skull detached and placed on a fire-hardened adobe building block in the western corner (Figure 4D). The individual respresented may have been decapitated prior to burial, or his skull may have been detached and placed in the western corner at the time the second burial was made (Figure 4E). Subsequently, the ''roof'' of the crypt had been broken in and a second interment made, a secondary bundle burial of an adult male placed in an upright position, near the western corner, facing east. The crypt ''roof'' was rebuilt, using in part poles from the earlier roof, judging by the evidence of radiocarbon dates.

Thereafter, the crypt ''roof'' was breached again and a third interment (Figure 4E), again, a bundle burial, was made, practically sitting in the lap of the second burial. The crypt roof was replaced again, and as before, some poles from the earlier roofs may have been reused.

If the evidence of the radiocarbon dates, to be discussed later, is to be accepted at face value, it was the time of the second burial that the Temple of the Crypt, surrounding and enclosing the original ''sarcophagus'', was constructed, inasmuch as the radiocarbon dates for three of the survey stakes used in laying out the walls of the temple correspond to at least one, probably two, of the poles used in construction of the second ''roof'' of the ''sarophagus.''

Thereafter, probably as an accompaniment to the third burial, a later temple (the Crenelated Temple) was constructed. The earlier temple was torn down and its component adobe building blocks and wall-top merlons were used as fill for an extension of the basal platform which enclosed the underlying basement structure.

Figure 1. Aerial views of Alta Vista. A. View from southeast after end of 1974 excavations. B. View from northwest near the end of 1975-76 excavations. ''P'' marks pyramid, Structure No. 2B, in both views. (A. Photograph courtesy of Morrison Limon Boyce and C.E.T.E.N.A.L. B. Photograph courtesy of Drs. Alejandro Peschard, Jaime Bodat, and Jesus Lazalde)

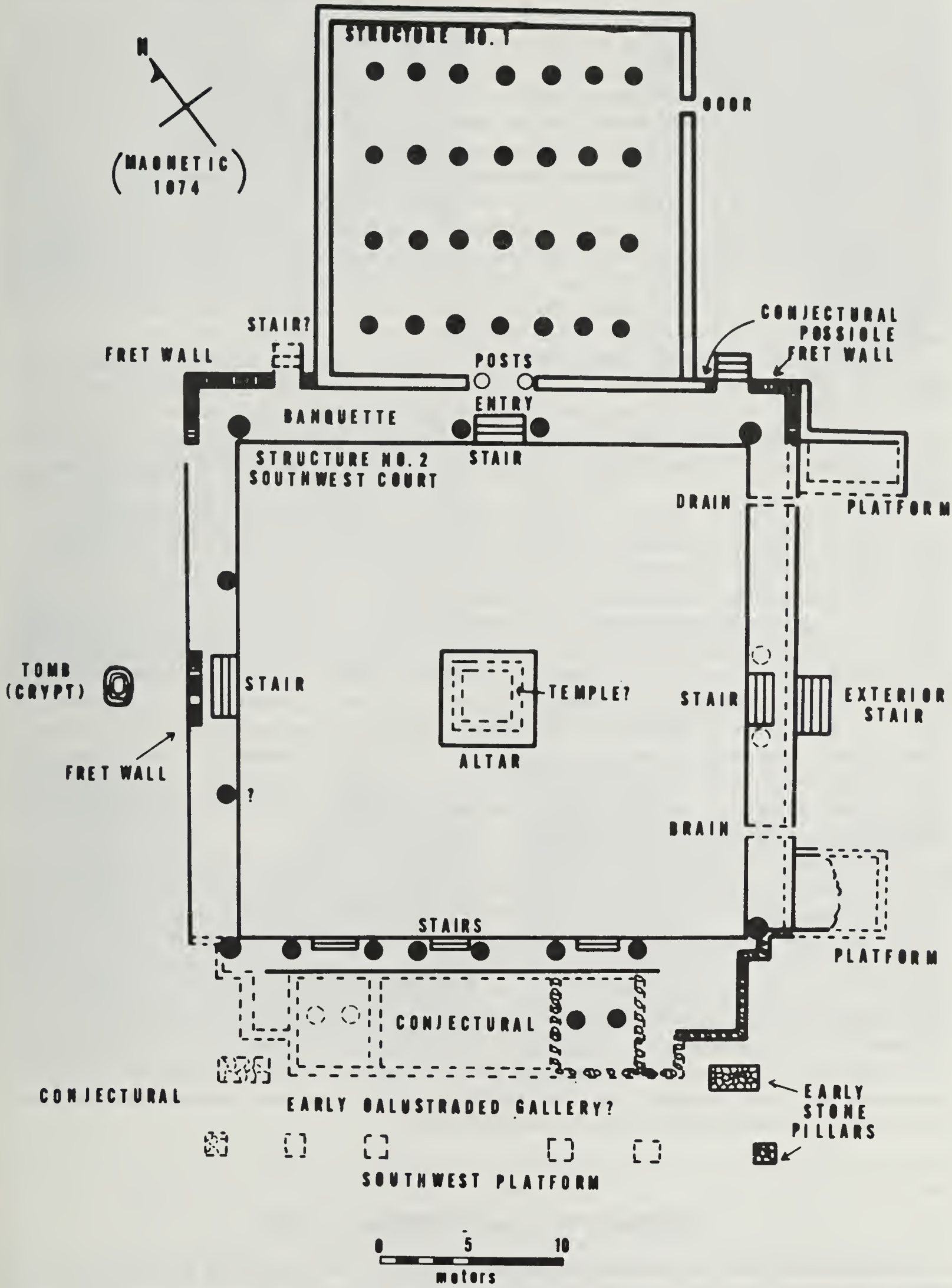


Figure 2. Plan of postulated nuclear section of Alta Vista, showing earliest construction.

The axis of the Crenelated Temple was constructed at right angles to that of the earlier Temple of the Crypt. The earlier basement structure was retained, but front and back walls of the new structure were built crossing over the basement area below. Where the longitudinal walls of the superimposed structure crossed the stone masonry basement walls, cuts were made in the latter and in these cuts large wooden beams were placed, crossing the open basement area and serving as footings for the adobe brick walls of the new temple. Either the architect overestimated the load capacity of these beams or else they were weakened by decay over a considerable period of usage. Whatever the cause, the basal supporting beams gave way, the adobe brick walls which they supported collapsed and the crenelated end walls fell top first, into the basement. The tops of these end walls were crenelated like a medieval castle, hence the name, the Crenelated Temple.

A variety of offerings accompanied the three burials, all of which occupied the western section of the crypt, with their skulls facing roughly toward the east. A section of a red obsidian sacrificial knife lay on the basement floor. Above the crypt cover, at its western end, was a large conch shell trumpet (Figure 4F), and a wooden ''arrow'' (probably a prayer arrow, Huichol-style) stood upright in the western corner. Over the forehead and face of the third and most recent burial was a mosaic plaque, 10 cms. in diameter, resembling the sun symbol as often depicted in Mesoamerican art, With this burial we also found a turquoise-on-wood mosaic *bezote,* seven turquoise-on-wood rings, seven rings cut from nut hulls, a rim portion of a matting basket, fragments of gourds with pseudo-cloisonne decoration, a preserved piece of fabric shroud, and clay fragments with textile impressions.

With the intermediate or second burial, we found remains of a pyrite mirror with a two-piece stone back, a large turquoise-on-wood mosaic (disintegrated), a turquoise necklace, a ''turkey'' turquoise-on-wood mosaic pendant, 21 turquoise-on-wood rings, 72 pieces of rings cut from nut hulls (four complete) and a cache of chert flakes. With both burials No. 2 and No. 3 were found fragments of *petates.* With the original burial we found only a small bead ring, a cache of obsidian chips and a number of fragmentary rings of nut shell. It is possible that offerings originally placed with it were removed at the time of the second burial, or else were placed with the second individual. Throughout the burial area were found numerous small fragments of disintegrated fabrics. Also in the general burial area were four red pigment stones and one smoothed pebble. A shallow bowl or plate of polished black ware was the only ceramic piece accompanying the burials. If this shallow black bowl or plate originally had a very high polish it may have functioned as a mirror. It could not be assigned to a specific burial and neither it nor the other objects found provide a phase assignmment for the burials or the structure.

The crypt itself was never filled; building debris from the collapse of the superimposed structure (the Crenelated Temple) crashed through its cover and accumulated around the burials and on the floor. The ''basement'' room, from which the crypt was reached, showed no signs of other usage; its floor was relatively soft and in the area cleared there were no floor features. However, because we left in place one of the toppled end walls of the Crenelated Temple, a considerable area of the floor was not cleared. Presumably, the basement itself was reached through a hatchway in the temple floor; alternatively, the temple floors may have been breached when burials were made. Collapse of the overlying structure obliterated evidence of such an opening, if indeed there was one. Inspection of the plastered inner walls of this basement vault, after they had been exposed to weathering for a year, revealed that mural paintings in black may have originally covered them, but the nature of the paintings could not be determined.

SEQUENCE OF CONSTRUCTIONAL EVENTS

Note must be taken at this point regarding problems of dates and Alta Vista chronology in general. Prior to our excavation at Alta Vista itself, we had developed a regional chronology based on a large number of radiocarbon datings and general cultural cross-dating (Kelley and Kelley 1971, Plates 1 and 2).

In this regional chonology, the Alta Vista phase, which we then believed represented the sole occupation of the site, was dated with some uncertainty at A.D. 300-500. Excavations revealed that the principal occupation of the site occurred in the Canutillo phase, during which construction

A.

B.

C.

D.

E.

F.

Figure 3. Photos, Alta Vista. A. View of the phramid (Structure No. 2B) before excavation, stairway at left center. B. View of pyramid from front. Court, court altar (left) and unexcavated court fill in foreground. C. View of pyramid showing final stage of construction (left), alleyway with debris of burned skull rack, and Temple of the Hearths (right) D. North corner of pyramid. E. Pyramid stair after removal of final stage. Note break between early stair rising from court and later upper stair. F. Final face of stair during excavation. Note later stone offering box constructed after stair was covered with debris.

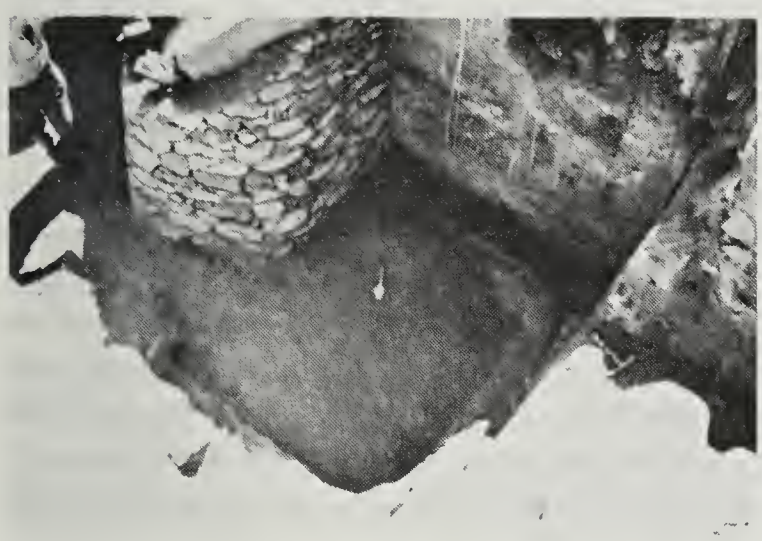
of the nuclear structures took place. There was somewhat puzzling evidence of a following brief occupation during the Vesuvio phase, and thereafter major expansion and remodelling of the ceremonial center took place during the Alta Vista phase, followed by a brief terminal occupation during the transition from the Alta Vista phase to the Calichal phase.

When the first 14 radiocarbon dates for Alta Vista were received, it was at once apparent that this putative regional chronology required drastic revision and that use of radiocarbon determinations to date the various phases represented there would be very difficult indeed. To test the reliability of the radiocarbon dating and the validity of inferences derived from it, we submitted to the Geochron Laboratories, as a test case, eleven specimens of wood whose place in the construction sequence of Structure No. 2B could be determined with considerable reliability. The results of this test indicated conclusively that radiocarbon dates obtained from structural elements should be handled separately from those obtained from refuse deposits, often mixed and of uncertain primary origins. Furthermore, even the sole use of structural elements still required the use of certain postulates, about which we remain somewhat skeptical, in developing actual inferences of age.

Thus, three of the survey stakes from the Temple of the Crypt gave almost identical central dates, averaging out to A.D. 835 (Geochron GX-4863, GX-4864, GX-4865). However, the average central date of three roof beams from the same structure was *circa* A.D. 558 (Geochron GX-4870, GX-4871, GX-4873), or 277 years *older* than the average date of the survey stakes used in laying out the structure. Because the roof beams were quite large, it may very well be that they were reused from an unknown structure built at that time. However, in the Hall of Columns, a survey stake from the interior upper northwest wall produced a central radiocarbon date of A.D. 495 (Geochron GX-3869), while a similar survey pole from the interior upper southeast wall of the same building produced a central date of A.D. 835 (Geochron GX-3868). Taken literally, this means that some 340 years elapsed between staking out (and presumably construction) of the northwest and southeast walls of the Hall of Columns. Even if the *upper* one sigma range of the earlier date, at A.D. 620, is compared to the *lower* one sigma range of the later date, A.D. 705, there still remains an interval of 85 years between construction of the two walls; furthermore, this type of manipulation of the radiocarbon dates seems unjustified. Reuse of an older pole in the northwest wall seems unlikely; we are concerned with a pole only 5-7 cms. in diameter and over 2 meters in length. Furthermore, a section of a thin roofing slat imbedded in burned adobe fallen from the roof of the Hall of Columns on the northwest side gave a central radiocarbon date of A.D. 560 (Geochron GX3877), which stands in reasonable relation to the cited early date of A.D. 495 for staking out the wall on that side of the structure. Again reusage of older wood seems highly improbable. The dates presented hereafter accordingly must be accepted with considerable reserve.

Figure 4. The basement room of the Temple of the Crypt, beneath the later pyramid. A. Basement room with back of stairway in center rear; older step-fret figure exposed by removal of wall plaster. At right, toppled south wall of the Crenelated Temple is supported by a stone-walled base to preserve it in place. B. View of the crypt, before excavation, viewed from slightly southeast of east. Crypt roof has not been fully cleared and appears relatively intact. Actually, beams from the collapse of the Crenelated Temple broke through it. Wall at right is support for toppled wall. C. Northwest interior wall of Temple of the Crypt. The large break first occurred when collapse of overlying Crenelated Temple pulled beam end from wall. Post-abandonment erosion further expanded the break. Toppled end wall of Crenelated Temple at left. D. First burial made in crypt, loosely flexed on back. Leg bones, and other bones have been removed. Skull is *in situ* on a building block in west corner, either placed there originally (decapitation?) or at the time of the second burial. E. Bundle burials Nos. 2 (left) and 3 in west quadrant of crypt. Note building block over skull of Burial No. 1. F. West inside corner of Temple of the Crypt basement room showing shell trumpet at edge of crypt. Cavity in which corner survey pole was found rises vertically in back center.

A.



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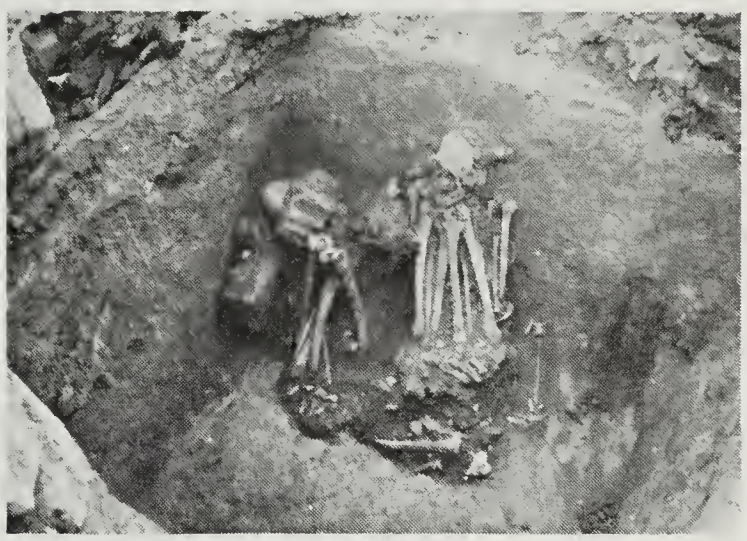


E.

F.

The following tentative sequence of events is inferred from structural position and radiocarbon datings (uncorrected), with the reservations previously noted.

(1). Initial construction of the nuclear units of Alta Vista began between *circa* A.D. 370-610, probably well before A.D. 495 (Geochron GX-3867), the central date for the survey pole used in construction of the northwest *upper* walls of the Hall of Columns. The oldest radiocarbon date from the site is A.D. 470 (315-625), obtained from a re-used beam. Construction of the northwestern part of the Hall of Columns and the adjacent banquettes of the Southwest Court (Structure No. 2) (Figure 2) was probably completed by *circa* A.D. 560 (Geochron GX-3877), the central radiocarbon date for a slat from the burned roof overhanging the northwest upper wall of the Hall of Columns. There is possibility that only the northwestern side of the structure was constructed and roofed during this period. There is architectural evidence that construction of the Southwest Court was completed as an integral part of the construction of the Hall of Columns.

(2). At approximately the same time, an unidentified structure was built, represented by the clustered dates of roof beams in the Temple of the Crypt (central dates of three beams, A.D. 525, Geochron GX-4871; A.D. 560, Geochron GX-4870; A.D. 590, Geochron GX-4873; average A.D. 558) which we infer were reused beams from an older structure in the context where they were found.

(3). Construction of the "sarcophagus"/crypt and burial therein of the first high status individual took place at *circa* A.D. 665-680 (Geochron GX-4866, GX-4869-reused in roof 3) (average A.D. 673), or at least after A.D. 530-565 and before A.D. 795-800 (Figure 5A).

(4). The upper southeast wall of the Hall of Columns was staked out and presumably constructed at A.D. 835 (Geochron GX-3868), or between A.D. 705 and 965. There is a possibility that this was a rebuilt wall replacing an earlier one removed for some reason. Giving some credence to this suspicion is the fact that the southeast wall is not attached at either end to the walls it abutts, in contrast to apparently integral corners on the north and west, and because the alignment of this wall is slightly different from that of the opposed northwest wall.

(5). Also survey stakes were placed for the Temple of the Crypt at *circa* A.D. 835 (Geochron GX-4863, GX-4864, GX-4865), the temple was completed and burial of the second high status individual was made at *circa* A.D. 840 (Geochron GX-4876, GX-4868-reused in roof 3). The Temple of the Crypt was constructed in two parts. The lower basement area was laid out with survey stakes and thick stone masonry walls were built to enclose the "sarcophagus." The long, narrow, rectanglar enclosure thus formed was filled with earth to the level of the top of the "sarcophagus," converting it into a crypt. A thin plaster floor was placed over this fill and the walls above it received a coat of lime plaster over an adobe facing coat. The southeastern end of this basal section abutted the exterior wall of the northwest banquette of the Southwest Court and extended upward and over the banquette, enclosing the three free-standing fret figures which had apparently been built at the same time as the banquette of the northwest side of the Southwest Court of Structure No. 2, on whose outer edge they had been placed. On the southeast, the former court stairway was extended upward to the level of the top of the basal construction, complete with balustrades on each side (Figure 5B). This basal platform was covered and on it was constructed a narrow-walled temple of adobe bricks, apparently topped by merlons. The construction of this earlier Temple of the Crypt, its nature, and the type of merlons that topped its walls is inferred from the debris used in extending the basal platform for construction of the later Crenelated Temple (Figure 5C).

Other clustered dates indicate widespread remodelling and expansion of the nuclear section of Alta Vista at about the same time. The inference is that accession to power of a new priest-ruler (high status burial No. 3?) following the death of his predecessor (high status burial No. 2) resulted in widespread building activity in keeping with the Mesoamerican pattern. Note that if the dates are taken as presented, the "sarcophagus"/crypt existed as a free-standing monument for some 165 years, which seems highly improbable. Variation of the radiocarbon dates of the two events within a one sigma range, however, would bring the successive burials close enough together temporally for them to represent a single ruling lineage, which seems probable because of their sequential burial within a single crypt. This would mean that the burial of the first individual is placed much too

early or that of the second individual too late by a century or more. The burial photographs do seem to indicate that a long time elapsed between the first and second burials (Figure 4D and 4E), but that the second and third burials were made in reasonably fast succession. When the exterior of the ''sarcophagus'' is excavated, its appearance may provide some clues to the length of time it may have existed as a free-standing structure.

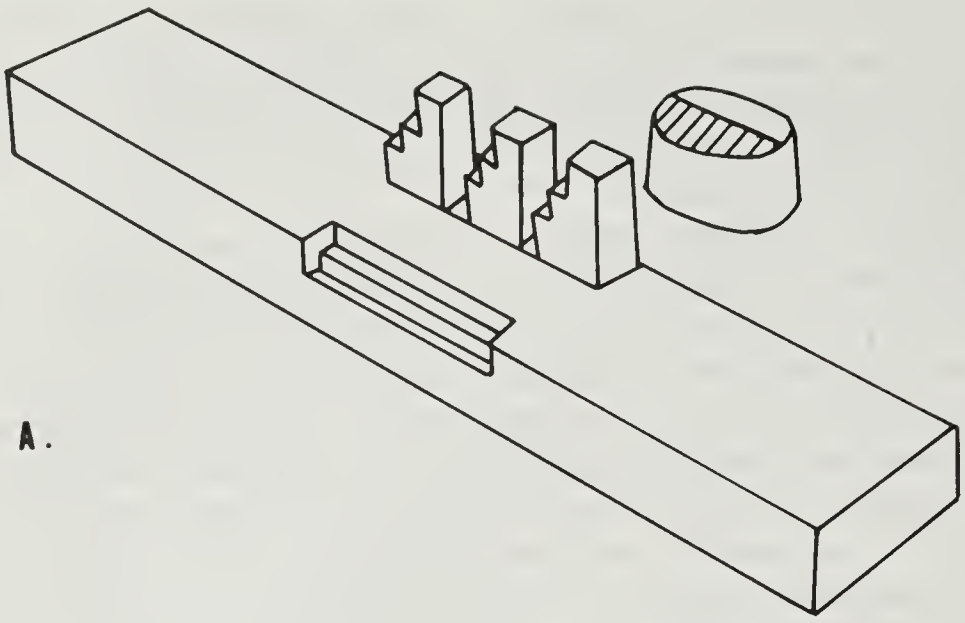
(6). A third high status burial was made within the crypt, and it appears reasonable that the superimposed Crenelated Temple was built at the same time. This Temple retained the basement and crypt of the Temple of the Crypt but was constructed with its long axis at right angles to that of its predecessor (Figure 6A). The adobe walls and merlons of the earlier structure were used as fill in extending the basal platform on which the new temple rested. As previously noted, where the adobe walls of the Crenelated Temple crossed over the basement and the crypt, they were supported on large beams set as footings in deep niches cut in the basal platform walls of the original structure. On each side of the stairway the enlarged basal platform of the new structure was extended almost to the banquette edge. We were able to find survey posts and the cast of a horizontal beam which were used to locate one of two terraces or steps with which the front of the new structure was faced. Actual facing stones have long ago disappeared but placement of remaining stones may indicate that the lower stage was markedly taluded while the upper stage was vertical (Figure 6B). We have no radiocarbon dates for the third burial or for construction of the Crenelated Temple, although datable specimens were obtained and remain in the collections stored in Zacatecas.

(7). Either the basal log supports of the Crenelated Temple broke under the superimposed weight almost immediately or after a long period of decay, or else the temple was deliberately destroyed. Whatever the cause, the front and back walls of the Crenelated Temple dropped, in part, into the basement and the crenelated end walls toppled in from both ends. The resulting debris largely filled the basement, covering the burial crypt and destroying its usefulness for subsequent burials. We have no dates for this event.

(8). The basal platform was then raised, the stairway was refaced, extending the lower step into the Southwest Court, and the platform was extended on three sides by building taluded walls, turning it into a true truncated pyramid, here termed the ''Sun Pyramid'' (Figure 6B). On the upper talud on the southwest, we found a formerly attached plaster and adobe sun disk. We have already noted the discovery of a sun disk mosaic with the third high status burial. One of the other mosaics apparently represents a turkey; in Huichol analogy, the turkey is the sacred bird of the sun (Furst and Scott 1975). One of the ''plaster glyphs'' (grafitti) discovered in the nearby Labyrinth, identified as an observatory concerned with equinox and summer solstice zenith sun observations (Kelley 1977 MS), was also that of either a turkey or an eagle. As in Huichol analogy, the corners of the Pyramid of the Sun are oriented to the cardinal points (as were those of the underlying structures) so that ''Padre Sol'' may climb his ladder (Furst and Scott 1975); the high status burials are grouped in the western quadrant of the crypt facing east toward the rising equinox sun, approximately in line with the axis of the Labyrinth. That the Pyramid of the Sun, as well as earlier structures buried beneath it, was concerned primarily with sun ceremonialism and that the high status individuals buried in the crypt were, in fact, sun-representatives seems strongly indicated.

Figure 5. Reconstruction of building stages of the earlier structures incorporated in the Pyramid of the Sun.

A. Architect's view of the Southwest Court banquette showing stair, stepped figures and postulated free-standing ''sarcophagus''.
B. Architect's view of the construction of the basal platform of the Temple of the Crypt.
C. Similar view showing postulated upper Temple of the Crypt.



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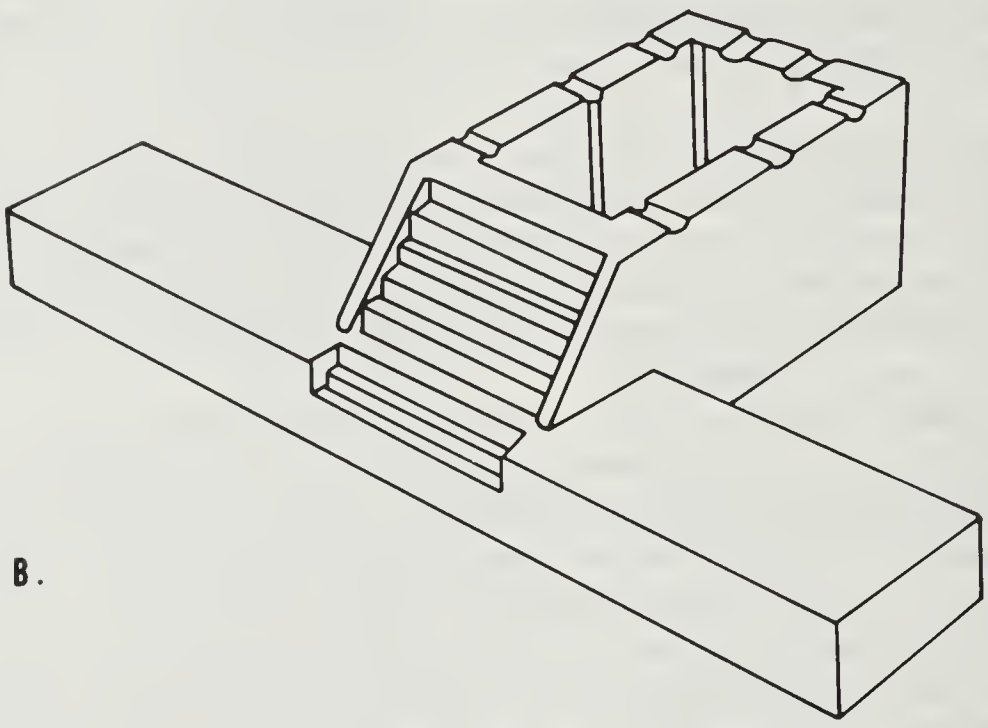

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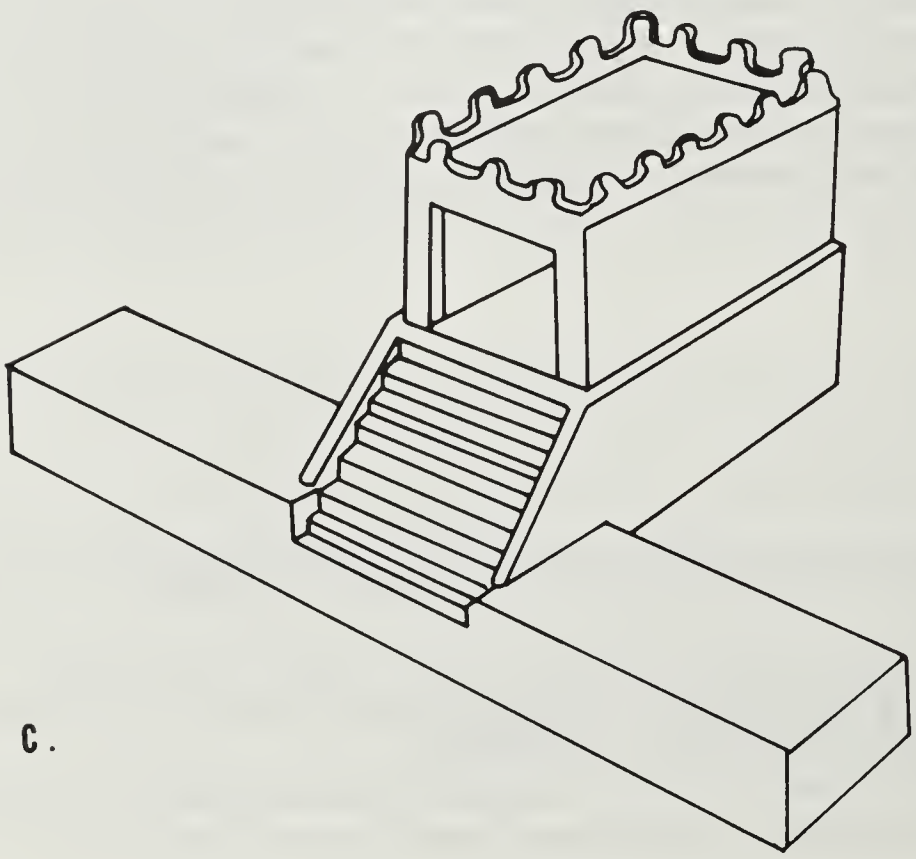


C.

(9). When the corridor lying between the Pyramid of the Sun and the adjacent temple on the northeast was excavated, the burned remains of what must have been a skull and long-bone rack was discovered. Beneath the junction of two charred beams of this frame lay a human cranium, pierced near its apex for suspension. Other pierced human crania, as well as long-bones, were discovered in the same general mass of debris and in the vicinity of the first cramium noted we recovered the proximal ends of two femurs retaining a wrapping of cord, presumably used in their suspension from the rack. In the Temple of the Skulls, the third member of the three-temple complex, situated adjacent to the Pyramid of the Sun on the southwest, evidence of another such rack was inferred from the placement of a large number of skulls and long-bones on the temple floor (Ellen Kelley 1978). In neither case could we determine whether the skull and long-bone rack was a separate structure, either vertical or horizontal, or was actually a part of the temple wall concerned. One sample of charcoal from the first skull rack noted had a radiocarbon date of A.D. 840, with a one sigma range of A.D. 705-975 (Geochron GX-3873); a second sample yielded a date of A.D. 470, between A.D. 315 and 625 (Geochron GX-3874). The latter specimen presumably was reused from an earlier construction, while the first specimen should more or less date the construction of the skull rack, although the central date of A.D. 840 seems much too early *relative to the dates of the underlying Temple of the Crypt;* a date in the tenth century would seem more acceptable in terms of the earlier dates, if indeed they are valid. Perhaps both samples represent reused timbers.

At any rate, the skull, and long-bone roof or temple wall burned and fell into the passage. Presumably the temple on the Sun Pyramid's uppermost top was destroyed and abandoned at the same time. We have no radiocarbon dates for these latter events. Perhaps at the same time, part of the putative ''palace'' of Structure No. 4 was destroyed by fire.

(10). After the stair of the Sun Pyramid was covered by some 20 cms. of debris, a small square stone box was built on it, apparently an offering box, although it was empty when excavated. This usage of the site as a post-occupational shrine may be correlated with a clearly post-occupational charcoal specimen recovered from the fill of the drain through the southeast platform of Structure No. 4. This specimen was radiocarbon dated at A.D. 1150, with a one sigma range of A.D. 1025-1275 (Geochron GX-3880).

CORRELATION OF BUILDING STAGES WITH CERAMIC PHASES

Correlation of ceramic phases with building stages, as outlined above, is difficult. The court floor and those of temple and platform surfaces were kept amazingly clean. The few vessel remains found in such contexts were undecorated and the wares represented occur throughout the ceramic sequence. Refuse, usually mixed with earth, stones, and other debris, was used to fill new platforms; this may have been derived from multiple sources. The basal platforms of early structures, including those of the three-temple complex, the banquettes, an attached exerior stair, the central altar of the Southwest Court, and the huge basal platform of the Hall of columns, produced only sparse decorated sherds of the Canutillo Phase, plus exotic sherds of Vista Pseudo-cloisonne and Negative A wares (Kelley and Kelley 1971, Kelley 1974, Holien 1975, 1977 MS, Holien and Pickering 1978). If one assumes that all ceramic types currently in use would have been included in the huge mass of fill represented, all of these structures would be assignable to the Canutillo phase, including the Temple of the Crypt. This, however, is a dangerous assumption; only refuse dumps of that phase may have been used as sources of fill.

We are also faced with the question of the origin of the Canutillo phase refuse found in the fill of the nuclear structures. In the field, we assumed that the ceremonial center had been constructed on the site of an earlier Canutillo phase village, whose refuse provided fill for the new construction. Yet we found no remains of earlier structures in place and only a few pieces of adobe showing marks of *jacale* walls or roofing. Furthermore, such an interpretation again confronts us with a contradiction in radiocarbon dates. Thus, as previously noted, the putative construction date for the upper northwest wall of the Hall of Columns was *circa* A.D. 495, with a one sigma range of A.D. 370-620 (Geochron GX-3869). However, the radiocarbon date of a non-constructional charcoal sample derived from the *fill* of the *basal* platform of the Hall of Columns was A.D. 670, with a one sigma range of A.D. 550-790 (Geochron GX-3867). A more likely hypothesis is that the Canutillo

phase refuse used in filling early platforms was actually the debris of a contemporary work camp. Accepting this view, the upper walls of the Hall of Columns may have actually been built before the basal platform was filled completely with debris. Obviously, more data are required to resolve this question.

Throughout much of the nuclear construction area, later pits dug into these early platforms, especially in the Hall of Columns, produced sherds of Alta Vista phase ceramic types. Certainly, constructions dating to the great remodelling of the nuclear area and general extension of the site, associated previously in this discussion with construction of the Crenelated Temple and the second high status burial in the crypt, are associated with deposits producing Alta Vista phase ceramic types. But in the platforms meeting at the southern corner of the Southwest Court, platforms containing only Canutillo phase ceramic associations have platforms producing ceramic association of both the Canutillo and Vesuvio phases superimposed upon them. On these, in turn, are superimposed structures which contain ceramics of the Alta Vista phase. Curiously enough, then, while the general sequence of phases found throughout the site is Canutillo phase followed by Alta Vista, we have an intervening Vesuvio phase occupation represented in very restricted areas. There must exist elsewhere in the site structures whose occupation produced the Vesuvio phase refuse. Presumably these represent a period of occupation falling between the Canutillo and Alta Vista phase occupations. However, we must not completely ignore the possibility that the Vesuvio phase occupation was contemporaneous with part of either the Alta Vista phase occupation or the earlier Canutillo phase occupation, like the Oaxacan *barrio* at Teotihuacan (Millon 1973: 41-42).

We have a number of radiocarbon dates from charcoal found in refuse containing sherds of these three phases. We do not know what these charcoal fragments represent nor do we know that they were originally associated with the sherds in question.

Realizing these limitations, we have the following putative radiocarbon dating of refuse of the various ceramic phases. In Canutillo phase association, we have center dates of A.D. 670 (Geochron GX-3867) from the Hall of Columns platform fill, A.D. 695 (Geochron GX-3871) from an old sealed stairway fill, and A.D. 845 (Geochron GX-3870) from the fill of the altar of the Southwest Court. Aside from the lateness of these dates, they do seem to associate fairly well with the building periods up to and including the construction of the Temple of the Crypt and the associated major period of remodelling of the nuclear area which we have otherwise attributed to the Alta Vista phase. But the one central date from deposits containing ceramics of the Vesuvio phase, demonstrably following the Cantuillo phase, is A.D. 630 (Geochron GX-3875), with a one sigma range of A.D. 500-760, which would place it early or centrally in the indicated Canutillo phase time span. And the one non-structural date clearly coming from Alta Vista phase refuse derives from Structure No. 3, just southeast of Structure No. 2. Its central date is A.D. 740 (Geochron GX-3876), its one sigma range is A.D. 585-895, placing it approximately contemporary with the Canutillo phase dates. The problem of ceramic phase dating and association of ceramic phases with building stages at Alta Vista remains unsolved.

SIGNIFICANCE OF STRUCTURES AND BURIALS DISCOVERED BENEATH THE SUN PYRAMID

The high status burials found in the Temple of the Crypt must represent, in the Mesoamerican pattern, the ceremonial interment of ruler-priest-god-representatives, probably constituting a single lineage of Alta Vista rulers and priests of the sun. The Temple of the Crypt and its successor, the Crenelated Temple, then becomes quite interesting indeed. Above was the Temple where the living priest of the sun officiated. When he died, he was buried in a crypt in the underworld (basement) below the Temple, only to be succeeded by a new representative of the sun in the Temple above. Truly, the gods disappeared through the floor of the Temple only to emerge once again as the living deity. The dead spirits remained below the Temple in the underworld; the hatchway (or possibly a temporary floor opening) served as the entrance to the spirit world, into which the god-representatives vanished and from which they emerged again.

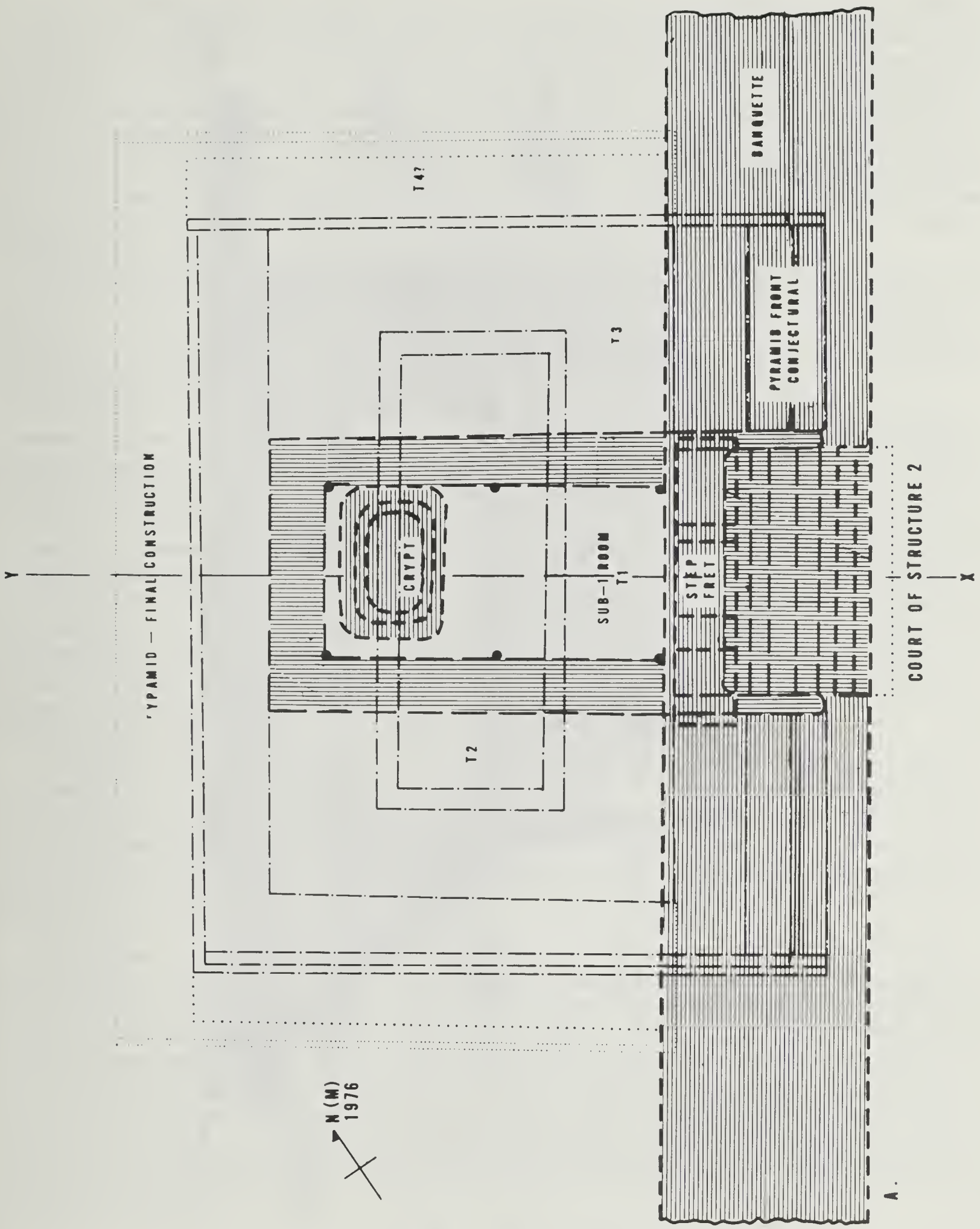
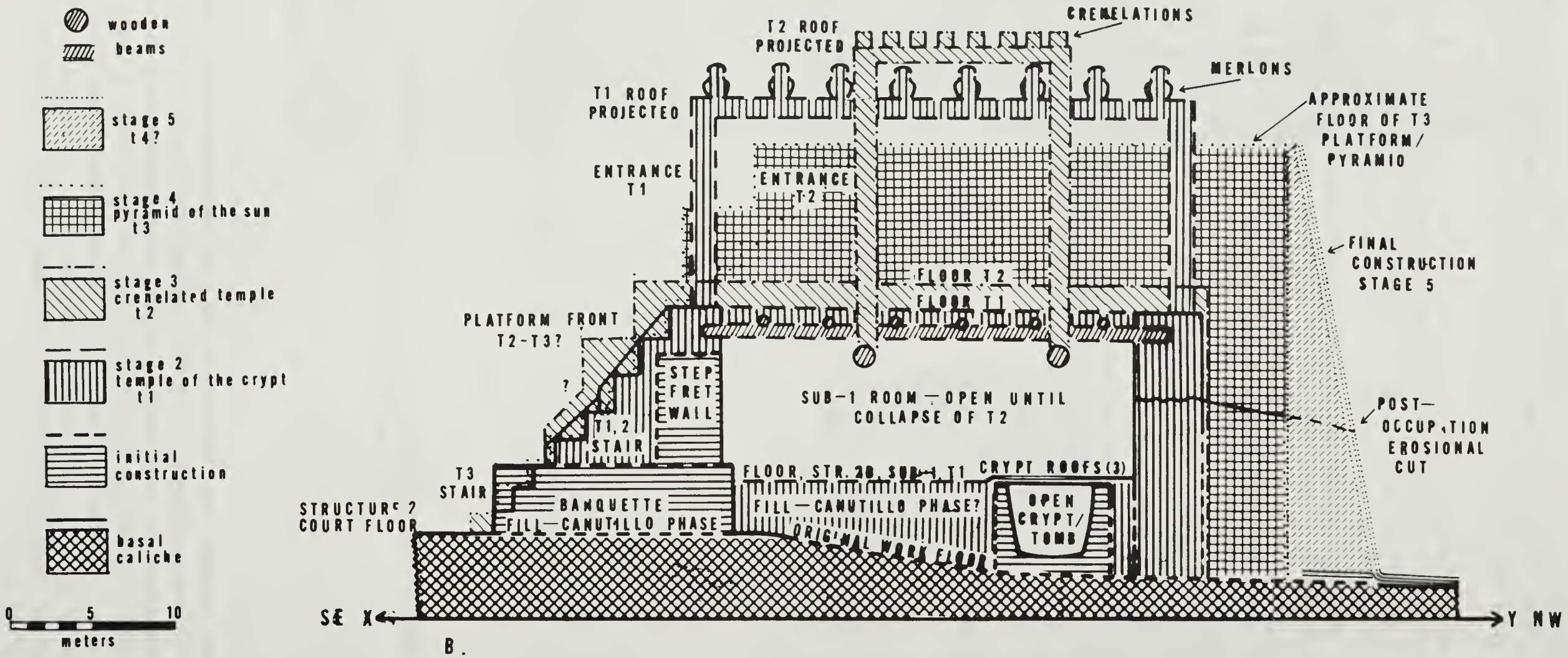


Figure 6. Plan and cross-section of Pyramid of the Sun, showing postulated construction stages. Front of pyramid is largely conjectural. For lack of sufficient data the final temple (T3) is not shown at all. A. Plan. Walls shown for interval stages are known for most part from exposures at surface and from test cuts. The Temple of the Crypt, better known, is given special emphasis in the plan. B. Cross section. The door and elevation of the Temple of the Crypt are entirely conjectural. The walls and roof of the Crenelated Temple are restored approximately from measurement of toppled walls. Fill in basement room is not shown.


wooden beams
stage 5 t4?
stage 4 pyramid of the sun t3
stage 3 crenelated temple t2
stage 2 temple of the crypt t1
initial construction
basal caliche
0 5 10
meters
CRENELATIONS
T2 ROOF PROJECTED
MERLONS
T1 ROOF PROJECTED
APPROXIMATE FLOOR OF T3 PLATFORM/ PYRAMID
ENTRANCE T1
ENTRANCE T2
FINAL CONSTRUCTION STAGE 5
FLOOR T2
FLOOR T1
PLATFORM FRONT T2-T3?
STEP FRET WALL
SUB-1 ROOM — OPEN UNTIL COLLAPSE OF T2
POST-OCCUPATION EROSIONAL CUT
T1,2 STAIR
T3 STAIR
FLOOR, STR. 28, SUB-1, T1 CRYPT ROOFS(3)
BANQUETTE
FILL — CAMUTILLO PHASE
FILL — CAMUTILLO PHASE?
OPEN CRYPT/ TOMB
STRUCTURE 7 COURT FLOOR
ORIGINAL WORK FLOOR
SE X
Y NW

B.

This conceptualization is in good Mesoamerican cultural tradition; it is also basic to Anasazi-Puebloan ceremonialism in which the sipapu in the kiva floor represents the spirit entrance to the underworld. In Huichol analogy, the effigy of the dead Fire God/Sun God occupied a cavity placed beneath or near the fireplace of the God-House (Parsons 1939:2:1012-1013); as indeed the Temple firehearth may have been the entrance to the basement and the crypt where the actual gods lay buried. Alternatively, in Huichol, a small statue of the God of Fire of the World Below is placed in a pit located in the center of the Temple of the God of Fire; the pit is covered with a circular stone disk (as is the sipapu in some Pueblo kivas) set flush with the floor. On this disk stands a statue of the God of Fire of the World Above (the sun) (Lumholtz 1973:/1902/:II:166, 169-171). The sipapu analogy is very clear.

The rectangular Temple of the Crypt with its stone masonry basal walls must certainly be regarded as analagous to the Anasazi rectangular kiva; its putative hatchway or ''opening of opportunity'' to the underworld as analagous to the sipapu. Clearly, basic ceremonial concepts were shared by Mesoamerican Chalchihuites and Southwestern Azasazi-Pueblo, as well as by intermediate Huichol.

But Alta Vista, the rectangular two-story Temple of the Crypt evolves into a Mesoamerican pyramid (Figures 5 and 6). If we should follow the example of some contemporary Southwestern archaeologists and consider the Chalchihuites culture as an independent universe in our research design, we might well take the position that here we have proof of the original invention, or an independent invention, of the Mesoamerican pyramid. To so conclude would be ridiculous; one must consider the Mesoamerican whole as the universe, the Chalchihuites culture on the northwestern frontier only as a cultural enclave participating to some degree in the main line of developments of Mesoamerican civilization. Indeed, the closest parallel to the Chalchihuites situation described is represented in the Teotihuacanoid structures at Kaminaljuyu near the southeastern frontier of Mesoamerica in highland Guatemala. There too, the priest-rulers, who (as at Chalchihuites, we believe) were also Teopthuacan merchants, were buried in crypts beneath the temple floor or beneath its fronting stairway complex. There also the succeeding ruler constructed a new temple beneath which he, in turn, was buried (Kidder, Jennings, and Shook 1946).

And as for central Mesoamerica itself, Richard E. W. Adams (1977:190) prefaces his section on Teotihuacan by quoting from Sahagun: ''And there (Teotihuacan) all the people raised pyramids for the sun and the moon; then made many small pyramids where offerings were made . . .And when the rulers died, they buried them there. Then they built a pyramid over them . . .For so it was said; 'When we die, it is not true that we die; for still we live; we are resurrected. We still live; we awaken.'' (Sahagun. Book 10, 1961:191).'' The Alta Vista situation could not better be described!

The Temple of the Crypt, then, is fully Mesoamerican in its broadest ceremonial and architectural aspects and developments. But it stands in relation to the grandeur and monumental aspects of Teotihuacan as does the Southwestern kiva to the Temple of the Crypt. Both share fundamental concepts in architecture and ceremonialism that diminish in complexity in ratio to their distance from the great centers. That structure which develops into a pyramid in Alta Vista is reduced to a kiva in the Anaszai; both have, conceptualy at least, their sipapus. The situation at Alta Vista once again demonstrates the magnitude of fundamental traits shared by the cultures of the American Southwest and those of Mesonamerica. Intellectually, one must regard the Southwestern cultures as minor participants in the complex and territorially extensive mighty cultural interaction sphere of Greater Mesoamerica!

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Effects of Temperature on Development and Reproduction in *Euschistus tristigmus tristigmus* (Hemiptera: Pentatomidae) with Notes on Reproductive Behavior[1]

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ABSTRACT

E. t. tristigmus adults were collected in Jackson Co., Illinois, and their offspring reared in the laboratory at 22, 27, or 32°C. The optimal temperature for development appears to be between 27 and 32°C.

The effects of the 3 temperatures on reproduction were also studied. Total and rate of fecundity were highest at 22 and lowest at 32°C; rate decreased over time at the 3 temperatures. Total percent fertility at 22°C was equal to that at 27°C, and higher than at 32°C. Total percent hatch of all eggs was highest at 22 and lowest at 32°C, and of fertile eggs highest at 22 and equal at 27 and 32°C. Oviposition periods were longest at 22 and shortest at 32°C, while preoviposition and postoviposition periods were not affected differently by the 3 temperatures.

Precopulatory and copulatory behaviors were observed between 6 pairs of animals.

INTRODUCTION

The phytophagous pentatomid *Euschistus tristigmus* occurs from northern Canada to southern Mexico (Van Duzee 1904) and includes 2 subspecies: *luridus* Dallas is found north, and *tristigmus* (Say) south, of the 41st parallel (McPherson 1976). Thus *E. t. tristigus* occurs in southern Illinois.

Various aspects of the biology of *E. t. tristigmus* have been studied including life cycle and/or rearing under controlled conditions (Esselbaugh 1948; McPherson 1971, 1975a; Woodside 1946), and role of photoperiod in producing adult dimorphism (McPherson 1974, 1975b, 1979a, b; McPherson and Vangeison 1975). However, the effects of temperature on development and reproduction have not been investigated. Thus, the present study was conducted to determine the effects of 3 temperatures on these parameters. Also, notes were taken on the precopulatory and copulatory behaviors.

[1]Data included in this paper are part of a thesis submitted to Southern Illinois University at Carbondale by the senior author in partial fulfillment of the requirements of the M.A. degree in Zoology.

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MATERIALS AND METHODS

E. t. tristigmus adults were collected during June 1979 from common mullein, *Verbascum thapsus* Linnaeus, in Jackson Co., Illinois. They were placed in mason jars (5 males and 5 females per jar) and held in incubators maintained at 27 ± 1.2°C and a 16L:8D photoperiod. The mason jars were furnished with paper toweling and filter paper for absorption of excrement and additional walking surface, and green snap beans, *Phaseolus vulgaris* Linnaeus, for food, as described by McPherson (1971). All experiments described below used mason jars prepared similarly to those for maintaining field-collected adults. Cheesecloth was provided as an oviposition site for these adults and for those in subsequent experiments. Incubator temperatures (given below without ranges) were 22 ± 1.3, 27 ± 1.2 and 32 ± 1.9°C.

Effects of Temperature on Development Rate

Forty male and 40 female P_1 adults were selected from the offspring of field-collected adults, placed in mason jars (5 of each sex/jar), and maintained at 27°C in a 16L:8D photoperiod. Cheescloth with attached egg clusters was removed daily and placed on moist filter paper in petri dishes (ca. 9 cm. diam., 2 cm. deep). The dishes were placed in a 16L:8D photoperiod at 22, 27 or 32°C. The 1st instars (a nonfeeding stage) were also kept in the dishes. Distilled water was added every 1-3 days to maintain high humidity. The 2nd through 5th instars were reared to adults in mason jars at the same temperature as the eggs and 1sts. Each jar contained nymphs that had hatched from the same egg cluster. The lengths of stadia were determined for all instars by recording daily the number of exuviae. Stadia were statistically compared within and between the 3 developmental temperatures.

Effects of Temperature on Reproduction

Twenty F_1 generation male and female adults were selected from each of the 3 developmental temperatures (22, 27, 32°C) and isolated by pairs in mason jars in their respective temperatures; these were later supplemented with additional pairs as mortality among the original pairs occurred. Of these, 18, 25 and 14 pairs survived and reproduced in 22, 27 and 32°C, respectively. The resulting egg clusters were placed in petri dishes, as described above, and incubated until hatching; these eggs provided data on fecundity, fertility and hatch per female. Fecundity was defined as the number of eggs laid, fertility as the percent of eggs that developed eye spots, and hatch as the percent of eggs laid (and percent of fertile eggs laid) that successfully completed development. Also recorded were the preoviposition, oviposition and postoviposition periods. The preoviposition period was the time between the final molt (adulthood) and the 1st oviposition, the oviposition period the time between the 1st and final ovipositions, and the postovipostion period the time between the final oviposition and death.

Most comparisons of temperature effects on reproduction were based only on data collected during the 1st, 12, 12 and 8 weeks of oviposition period at 22, 27, and 32°C, respectively, the length of time being determined by the rate of mortality. Data collected beyond these periods were statistically weak since the numbers of surviving females were low.

Total fecundity, fertility and hatch, and the lengths of the preoviposition, oviposition and postoviposition periods, were compared between temperatures; fecundity, fertility and hatch were also compared between weeks within each temperature. Also, since lengths of oviposition periods varied within each temperature, each period was divided into quarters, and the fecundities compared, to determine if the rate of fecundity changed in each temperature during the oviposition period. Finally, the daily rates of fecundity in the 3 temperatures were compared.

Reproductive Behavior

Ten male and 10 female F_1 adults were separated by sex and maintained in 2 mason jars at 27°C and a 16L:8D photoperiod. A minimum of 3 weeks was allowed for maturation of the reproductive

systems. Subsequently, a male and female were placed in a petri dish and observed for mating behavior. If copulation occurred within 30 minutes, the pair (still within the dish) was returned to the incubator and checked 3-5 times per day until copulation ended (usually within 2 days). Otherwise, each animal was returned to its respective mason jar and a new pair selected for observation. Ten pairs were observed during this study, 6 of which exhibited precopulatory and copulatory behaviors.

Statistics

Data that consisted of counts (e.g., fecundity) were analyzed with the χ^2 one-sample test (Siegel 1956), and the remaining data (e.g., developmental rate) with Kramer's extension of the multiple range test for unequal sample sizes (Kramer 1956). The 0.01 level of significance was chosen because of high individual variation between animals.

RESULTS AND DISCUSSION

Effects of Temperature on Developmental Rate

Lengths of the egg, 1st and 2nd stadia were longest at 22 and shortest at 32°C (Table 1). The 3rd, 4th and 5th stadia were longest at 22 but shortest at 27°C, supporting the conclusion of Davidson (1944) that harmful effects of high temperatures are greater in the more advanced stages of the life cycle. The total developmental period from egg to adult averaged 50.56, 33.62 and 35.13 days at 22, 27 and 32°C, respectively. The above results suggest that the optimal temperature for total development is between 27 and 32°C.

The 1st and 5th stadia were shorter and longer, respectively, within each temperature than the remaining stadia (Table 1); these results agree with the findings of McPherson (1971) who reared this insect at 23.9°C. No other patterns within or between temperatures were found.

Effects of Temperature on Reproduction

Fecundity

Egg cluster sizes averaged 16.4, 12.9 and 7.8 eggs at 22, 27 and 32°C, respectively, and were significantly different from each other (22 vs. 27°C, $\chi^2 = 222.4$; 27 vs. 32°C, $\chi^2 = 206.8$). Fourteen was the most frequent cluster size and represented 29.4, 37.7 and 19.7% of the clusters laid at 22, 27 and 32°C, respectively (Fig. 1A-C).

Mean cluster size at 27°C did not change over time during the recorded oviposition period (Table 2). Mean cluster size at 22°C was generally smaller during weeks 7-12 of the oviposition period, particularly during weeks 10-12. The number of clusters laid after 5 weeks by 32°C females was insufficient for statistical analysis. However, during the 5 weeks, mean cluster size changed over time and was smallest during weeks 1-2, and largest during week 3.

Total fecundities averaged 374.5, 219.2 and 67.6 at 22, 27 and 32°C, respectively, and were significantly different from each other (Table 3).

To determine if the differences in total fecundity between temperatures were due to different rates of fecundity and/or different lengths of oviposition periods, both were compared between temperatures. Rate of fecundity for each temperature (listed in Table 4) was calculated as a mean daily rate by dividing the total fecundity for that temperature by the corresponding total of the oviposition period length. However, the actual χ^2 comparisons between temperatures were made using observed and expected total fecundities for each temperature.

The results show that rate of fecundity was highest at 22, and lowest at 32°C (Table 4). Also, the oviposition period was longest at 22, and shortest at 32°C (Table 9). These results clearly explain the differences in fecundity between the 3 temperatures.

Weekly fecundities at 22 and 27°C showed no consistent pattern during the 1st 12 weeks of oviposition (Table 5). However, fecundities were generally lower during weeks 7-12, and particularly during weeks 10-12. Fecundities at 32°C showed a similar pattern over time to those

Table 1. Comparison of the effects of temperature on lengths (in days) of developmental stadia of *E. t. tristigmus.*[1]

	Temperature (°C)					
	22		27		32	
Instar	N	Stadium[2,3]	N	Stadium[2,3]	N	Stadium[2,3]
Egg	759	8.50 ± 0.03^{a}	828	5.37 ± 0.02^{a}	787	4.01 ± 0.01^{a}
Nymph						
1st	610	4.99 ± 0.04^{b}	716	3.03 ± 0.01^{b}	685	2.69 ± 0.02^{b}
2nd	245	8.37 ± 0.08^{a}	279	6.03 ± 0.09^{c}	368	5.24 ± 0.08^{c}
3rd	228	7.49 ± 0.07^{c}	270	5.34 ± 0.10^{d}	277	6.26 ± 0.14^{d}
4th	220	8.54 ± 0.09^{a}	262	5.72 ± 0.10^{e}	226	7.19 ± 0.17^{e}
5th	199	12.67 ± 0.15^{d}	242	8.13 ± 0.10^{f}	196	9.74 ± 0.27^{f}

[1] All comparisons within stadia between temperatures (not shown here) were significantly different at the 0.01 level of probability by Kramer's extension of the multiple range test for unequal sample sizes.

[2] Stadia within temperatures followed by the same letter are not significantly different at the 0.01 level of probability by Kramer's extension of the multiple range test for unequal sample sizes.

[3] $\bar{X} \pm SE$.

of 22 and 27°C, but this pattern was limited to 8 weeks (e.g., fecundities during weeks 5-8 were lower than during weeks 1-4).

Comparison of fecundity between quarters of the 1st 12 weeks of oviposition showed that females at 22°C laid fewer eggs during the last quarter than during the first 3, those at 27°C progressively fewer eggs during the first 3 quarters, and those at 32°C fewer eggs during the last 2 quarters (Table 6).

Fertility

Total egg fertilities averaged 77.4, 76.7 and 24.0% at 22, 27 and 32°C, respectively; those at 22 and 27°C were nonsignificantly different, and were higher than that at 32°C (Table 3).

Fertility over time showed no pattern of change at 22°C and, in fact, was slightly higher during weeks 7-12 of the recorded oviposition period (Table 7); this increase was probably due to random variation. Fertilities in 27 and 32°C remained constant throughout the oviposition periods.

Hatch

Total percent hatches of eggs laid averaged 70.2, 65.0 and 20.3% at 22, 27 and 32°C, respectively, and were significantly different from each other (Table 3). Total percent hatches of fertile eggs averaged 90.7, 84.7 and 84.6% at 22, 27 and 32°C, respectively; that at 22°C was highest while those at 27 and 32°C were nonsignificantly different from each other (Table 3).

Percent hatch over time showed no pattern of change at 22°C and, similar to fertility, variation was probably random (Table 8). Percent hatch at 27°C did not change over time, while that at 32°C was higher during the last 3 weeks of the recorded oviposition period. We have no explanation for the increase at 32°C.

Preoviposition Period

The preoviposition periods averaged 19.6, 15.0 and 20.8 days at 22, 27 and 32°C, respectively, but were nonsignificantly different from each other (Table 9).

Oviposition Period

The oviposition periods averaged 77.8, 46.3 and 23.5 days at 22, 27 and 32°C, respectively, and were significantly different from each other (Table 9). As noted earlier, the 22°C females had

Table 2. Comparison of the effects of temperature on egg cluster size per week of *E.t. tristigmus*.

Temp. (°C)	Week	No. of Clusters	Eggs per Cluster[3]	Temp. (°C)	Week[2]	No. of Clusters	Eggs per Cluster[3]	χ^2 of weeks compared[1] 22°	22°	32°
22	1	53	15.0 ± 1.3	27	1	101	13.3 ± 0.7			
	2	35	15.4 ± 1.5		2	58	12.2 ± 0.8			
	3	32	18.2 ± 1.6		3	46	12.5 ± 0.9			
	4	35	19.0 ± 1.2		4	51	14.2 ± 0.7			
	5	36	17.6 ± 1.0		5	50	12.6 ± 0.8			
	6	32	17.1 ± 1.5		6	36	12.5 ± 1.1			
	7	42	17.6 ± 1.4		7	21	12.1 ± 0.9			
	8	30	17.4 ± 1.3		8	23	11.7 ± 1.6			
	9	33	14.1 ± 1.3		9	13	11.8 ± 1.1			
	10	26	15.9 ± 1.4		10	16	13.9 ± 2.0			
	11	31	13.8 ± 1.5		11	8	12.4 ± 2.6			
	12	13	13.4 ± 1.8		12	— —	— —			
	1-12							75.4*		
	1-6 vs. 7-12							15.5*		
	7-9 vs. 10-12							10.0*		
	1-11								17.1	
32	1	40	6.3 ± 0.8							
	2	36	6.8 ± 1.1							
	3	19	11.6 ± 1.3							
	4	13	9.4 ± 1.3							
	5	10	7.8 ± 2.2							
	6	— —	— —							
	7	— —	— —							
	8	— —	— —							
	1-5									54.4*
	1-2 vs. 3-5									41.0*
	3 vs. 4-5									8.6*

*Significant at the 0.01 level of probability.

[1]Comparisons were made between total egg counts, not means.

[2]Dashed line = insufficient data collected during corresponding week for inclusion in the statistical analyses.

[3]$\bar{X} \pm SE$.

the highest total fecundity of the 3 groups (i.e., 22, 27 and 32°C females) and this is explained by their having the highest rate of fecundity and longest oviposition period.

Postoviposition Period

The postoviposition periods averaged 5.3, 7.4 and 12.6 days at 22, 27 and 32°C, respectively, but were nonsignificantly different from each other (Table 9).

Adult Lifespan

The total of the 3 periods (i.e., preoviposition, oviposition and postoviposition) averaged 102.9, 64.1 and 52.4 days at 22, 27 and 32°C, respectively; those at 27 and 32°C were nonsignificantly different and were shorter than that at 22°C (Table 9).

Table 3. Comparison of the effects of temperature on total fecundity, egg fertility and hatch of *E. t. tristigmus*.

Temp. Parameter	(°C)	No. of Females	$\bar{X} \pm SE$	χ^2 of temps. compared[1] 22 vs. 27 vs. 32	22 vs. 27	27 vs. 32
Fecundity	22	18	374.5 ± 29.0			
	27	25	219.2 ± 22.3			
	32	14	67.6 ± 17.2	3239.6*	888.4*	1251.6*
Fertility	22	18	77.4 ± 7.4			
(%)	27	25	76.7 ± 5.2			
	32	14	24.0 ± 8.6	983. 5*	0.1	324.8*
Hatch (%) of eggs laid	22	18	70.2 ± 7.9			
	27	25	65.0 ± 6.4			
	32	14	20.3 ± 8.0	321.2*	12.0*	276.4*
Hatch (%)of fertile eggs	22	18	90.7 ± 6.4			
	27	25	84.7 ± 4.1			
	32	14	84.6 ± 12.0	9.7*	9.2*	0.0

*Significant at the 0.01 level of probability.
[1]Comparisons were made between total egg counts, not means.

Table 4. Comparison of the effects of temperature on daily fecundity (total fecundity/oviposition period) of *E. t. tristigmus*.

Temp. (°C)	No. of Females	Daily Fecundity[1]	χ^2 of temps. compared[2] 22 vs. 27 vs. 32	22 vs. 27	27 vs. 32
22	18	4.8 ± 0.3			
27	25	4.6 ± 0.4			
32	14	2.9 ± 0.4	224.4*	9.0*	173.8*

*Significant at the 0.01 level of probability.
[1]$\bar{X} \pm SE$.
[2]Comparisons were made between total egg counts, not means.

Table 5. Comparison of the effects of temperature on fecundity per week of *E. t. tristigmus*.

Temp. (°C)	Week	No. of Females	Fecundity[2]	Temp. (°C)	Week	No. of Females	Fecundity[2]	χ^2 of weeks compared[1] 22°	27°	32°
22	1	18	44.3 ± 4.7	27	1	25	54.4 ± 4.3			
	2	18	30.0 ± 4.0		2	24	30.0 ± 3.4			
	3	18	32.3 ± 5.3		3	24	24.5 ± 3.4			
	4	18	37.0 ± 3.9		4	21	33.9 ± 4.7			
	5	18	35.2 ± 3.9		5	21	30.0 ± 3.5			
	6	18	30.3 ± 4.6		6	19	23.7 ± 3.1			
	7	17	43.6 ± 3.6		7	16	16.7 ± 3.2			
	8	17	30.7 ± 4.2		8	13	20.3 ± 4.8			
	9	17	27.3 ± 4.4		9	12	13.8 ± 4.2			
	10	17	24.3 ± 4.7		10	10	21.6 ± 7.8			
	11	14	30.6 ± 4.8		11	9	9.3 ± 4.9			
	12	12	14.5 ± 4.2		12	6	4.7 ± 4.7			
	1-12							332.4*	1136.0*	
	1-6 vs. 7-12							55.4*	515.3*	
	7-9 vs. 10-12							120.3*	13.6*	
32	1	14	18.1 ± 4.0							
	2	14	17.5 ± 4.9							
	3	13	16.9 ± 5.4							
	4	10	12.2 ± 4.7							
	5	8	9.7 ± 3.6							
	6	8	0.6 ± 0.6							
	7	5	2.8 ± 2.8							
	8	3	0.3 ± 0 3							
	1-8									250.2*
	1-4 vs. 5-8									199.7*
	5-6 vs. 7-8									14.4*

*Significant at the 0.01 level of probability.

[1]Comparisons were made between total egg counts, not means. [2]$\bar{X} \pm SE$.

Table 6. Comparison of the effects of temperature on fecundity per quarter of oviposition period of *E. t. tristigmus*.

Temp (°C)	Quarter	No. of Females	Fecundity[2]	Temp. (°C)	Quarter	No. of Females	Fecundity[2]	χ^2 of quarters compared[1] 22°	27°	32°
22	1	18	103.7 ± 10.2	27	1	24	80.5 ± 8.6			
	2	18	97.7 ± 8.2		2	24	55.9 ± 8.3			
	3	18	98.9 ± 9.8		3	24	43.4 ± 4.6			
	4	18	75.6 ± 6.9		4	24	47.7 ± 6.0			
	1	12	25.7 ± 5.7							
	2	12	24.5 ± 7.3							
	3	12	13.4 ± 4.5							
	4	12	13.8 ± 3.8							
	1-4							90.3*	347.2*	81.6*
	1 vs. 2							3.2	106.8*	0.3
	2 vs. 3							0.1	37.7*	38.9*
	3 vs. 4							55.9*	4.7	0.1

*Significant at the 0.01 level of probability.
[1]Comparisons were made between total egg counts, not means.
[2]$\overline{X} \pm SE$.

Conclusions

The above results shows that although the optimal temperature for development of immatures appears to be between 27 and 32°C, those for high fecundity and a long oviposition period appear to be closer to 22°C. High temperature (i.e., 32°C) adversely affects fecundity, fertility, hatch and length of the oviposition period.

Reproductive Behavior

Precopulatory and copulatory behaviors were observed between 6 pairs of animals. Courtship was initiated by the male who usually began by antennating the female's antennae, but sometimes her head, thorax or abdomen. Contacts between the 2 were often sporadic at first but became more numerous. The male then moved to the female's side, antennating more rapidly than before. He occasionally moved back to her head or to her opposite side. Often there were long pauses during this period and sometimes one individual walked away from the other.

If the male continued antennating, either he would move to the end of the female's abdomen or she would turn her abdomen toward him. By this time, she usually had slightly elevated her abdomen. He then vigorously antennated her abdominal venter and she, if receptive, responded by lifting her abdomen usually 45 to 60° above the substrate. If he stopped antennating, she often lowered her abdomen. Throughout this period the male's abdomen vibrated up and down a short distance. His antennating of her venter lasted from a few seconds to ca. 3 minutes.

Next, the male extended and rotated his aedeagus 180° just before or as he turned 180°. He then lifted his abdomen to reach hers, and sometimes needed to twist the genital cup into place to initiate copulation. Sometimes he pushed at the end of her abdomen with his hind legs just after inserting his aedeagus.

Table 7. Comparison of the effects of temperature on egg fertility per week of *E. t. tristigmus*.

Temp. (°C)	Week[2]	No. of Females	Percent Fertility[3]	Temp. (°C)	Week[2]	No. of Females	Percent Fertility[3]	χ^2 of weeks compared[1] 22°	27°	32°
22	1	18	67.5 ± 9.8	27	1	25	71.6 ± 6.9			
	2	15	86.7 ± 5.7		2	24	68.7 ± 7.8			
	3	17	82.1 ± 7.8		3	21	78.8 ± 6.5			
	4	17	75.9 ± 7.0		4	19	81.3 ± 5.6			
	5	16	93.6 ± 6.5		5	20	82.9 ± 5.0			
	6	15	76.9 ± 8.2		6	17	78.7 ± 5.5			
	7	17	83.8 ± 8.5		7	12	81.7 ± 5.1			
	8	15	83.1 ± 7.2		8	11	83.9 ± 6.2			
	9	13	87.9 ± 7.4		9	8	84.1 ± 7.6			
	10	12	72.6 ± 8.7		10	7	69.9 ± 11.4			
	11	12	76.6 ± 8.4		11	3	82.2 ± 11.2			
	12	7	88.0 ± 9.1		12	— —	— —			
	1-12							55.6*		
	1-6 vs. 7-12							9.6*		
	7-9 vs. 10-12							4.6		
	1-11								22.1	
32	1	14	18.6 ± 9.4							
	2	12	22.4 ± 10.4							
	3	10	26.5 ± 11.4							
	4	5	34.6 ± 18.3							
	5	5	23.1 ± 19.3							
	6	— —	— —							
	7	— —	— —							
	8	— —	— —							
	1-5									9.7

*Significant at the 0.01 level of probability.

[1]Comparisons were made between total egg counts, not means.

[2]Dashed line = insufficient data collected during corresponding week for inclusion in the statistical analyses.

[3]$\bar{X} \pm SE$.

Table 8. Comparison of the effects of temperature on egg hatch (% of total eggs laid) per week of *E. t. tristigmus*.

Temp. (°C)	Week[2]	No. of Females	Percent Hatch[3]	Temp. (°C)	Week[2]	No. of Females	Percent Hatch[3]	χ^2 of weeks compared[1] 22°	27°	32°
22	1	18	63.5 ± 9.4	27	1	25	63.0 ± 7.4			
	2	15	78.9 ± 7.4		2	24	60.7 ± 8.4			
	3	17	69.3 ± 8.8		3	21	66.9 ± 7.3			
	4	17	70.9 ± 7.2		4	19	69.8 ± 8.0			
	5	16	79.8 ± 7.5		5	20	67.0 ± 7.9			
	6	15	71.3 ± 9.1		6	17	64.3 ± 8.6			
	7	17	72.0 ± 8.5		7	12	67.6 ± 8.5			
	8	15	74.0 ± 8.0		8	11	71.1 ± 10.0			
	9	13	78.9 ± 8.0		9	8	69.5 ± 12.6			
	10	12	73.6 ± 9.2		10	7	60.8 ± 14.5			
	11	12	67.4 ± 9.9		11	3	67.7 ± 20.1			
	12	7	78.7 ± 12.2		12	— —	— —			
	1-12							29.0*		
	1-6 vs. 7-12							5.6		
	7-9 vs. 10-12							4.8		
	1-11								19.9	
32	1	14	16.0 ± 8.5							
	2	12	18.7 ± 10.1							
	3	10	25.4 ± 11.4							
	4	5	32.7 ± 18.3							
	5	5	22.2 ± 18.6							
	6	— —	— —							
	7	— —	— —							
	8	— —	— —							
	1-5									14.8*
	1-2 vs. 3-5									164.8*

* Significant at the 0.01 level of probability.

[1] Comparisons were made between total egg counts, not means.

[2] Dashed line = insufficient data collected during corresponding week for inclusion in the statistical analyses.

[3] $\bar{X} \pm SE$.

Table 9. Comparison of the effects of temperature on lengths (in days) of preoviposition, oviposition and postoviposition periods of *E. t. tristigmus.* [1]

	Temperature (°C)					
	22°		27°		32°	
Period	No. of Females	Period Length[2]	No. of Females	Period Length[2]	No. of Females	Period Length[2]
Preoviposition	19	19.6 ± 1.0[a]	23	15.0 ± 0.8[a]	14	20.8 ± 2.6[a]
Oviposition[3]	18	77.8 ± 4.4[a]	26	46.3 ± 4.9[b]	14	23.5 ± 4.6[c]
Postoviposition	18	5.3 ± 1.5[a]	25	7.4 ± 1.6[a]	14	12.6 ± 3.0[a]
Total	18	102.9 ± 4.8[a]	22	64.1 ± 5.1[b]	14	52.4 ± 4.9[b]

[1] Means within periods between temperatures followed by the same letter are not significantly different at the 0.01 level of probability by Kramer's extension of the multiple range rest for unequal sample sizes.
[2] $\bar{X} \pm$ SE.
[3] Oviposition period based on total length of period per female, not just the first 12 weeks of oviposition.

If the male failed to insert, he usually turned back around and antennated the female's abdomen for ca. 10 to 30 seconds before again extending his aedeagus and attempting copulation. One male attempted to copulate 6 times before he was successful.

During copulation, the male often rested his hind tarsi on the female's hind legs or abdomen. The angle of their bodies with the substrate decreased from ca. 45 to near 0° (horizontal) within 1 to a few hours after copulation began. The pair did not remain stationary during copulation but moved about, the direction usually being controlled by the female. Copulation last from less than 36 to 48 hours or more, and both sexes fed during this time.

Two of the males vibrated from side to side for about 1 second, 2 to 3 times during courtship. One male, while vibrating, partially extended his aedeagus. Fish and Alcock (1973) reported that in *Chlorochroa ligata* (Say), a male will rapidly jerk his body while attempting to lift the female's abdomen with his head. Both sexes of *Brochymena quadripustulata* (Fabricius) jerk their bodies from side to side shortly after beginning copulation (Cuda and McPherson 1976, Gamboa and Alcock 1973). It would be interesting to know if the jerking motions observed in these 3 species are related, even though they occurr at different times during their mating behaviors.

No *E. t. tristigmus* male, during precopulation, even attempted to lift the female's abdomen with his head; this has also been reported for male *Murgantia histrionica* (Hahn) (Lanigan and Barrows 1977). However, it appears from the literature that lifting the female's abdomen in this manner is usually part of the male's precopulatory behavior (Alcock 1971, Cuda and McPherson 1976, Fish and Alcock 1973, Gamboa and Alcock 1973, Mitchell and Mau 1969, Vangeison and McPherson 1975, Youther and McPherson 1975).

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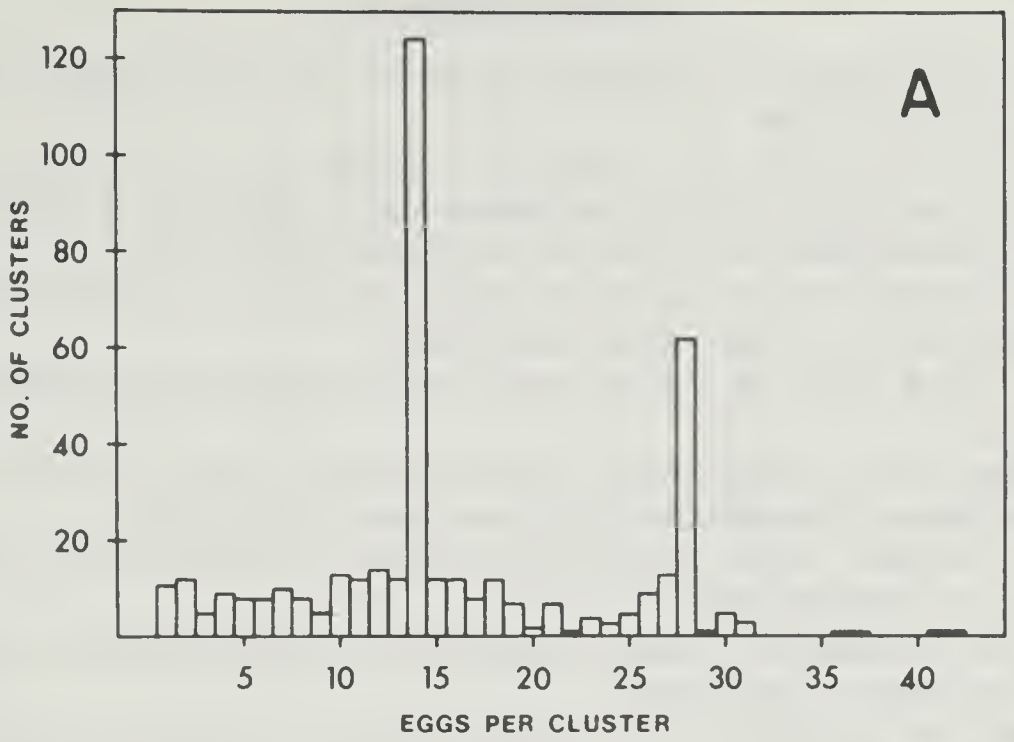

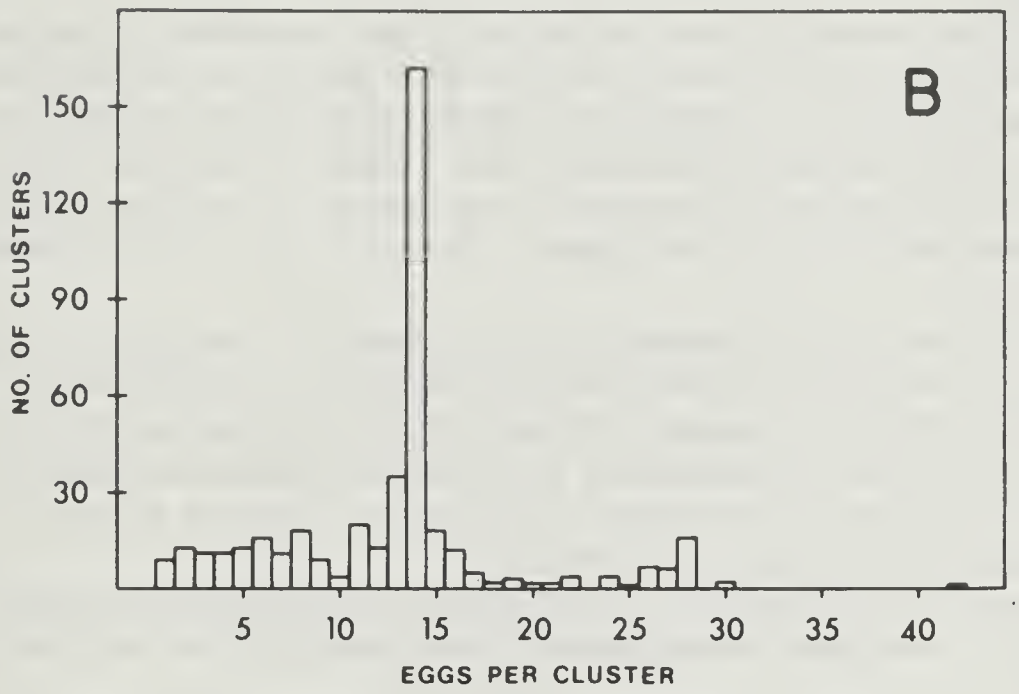

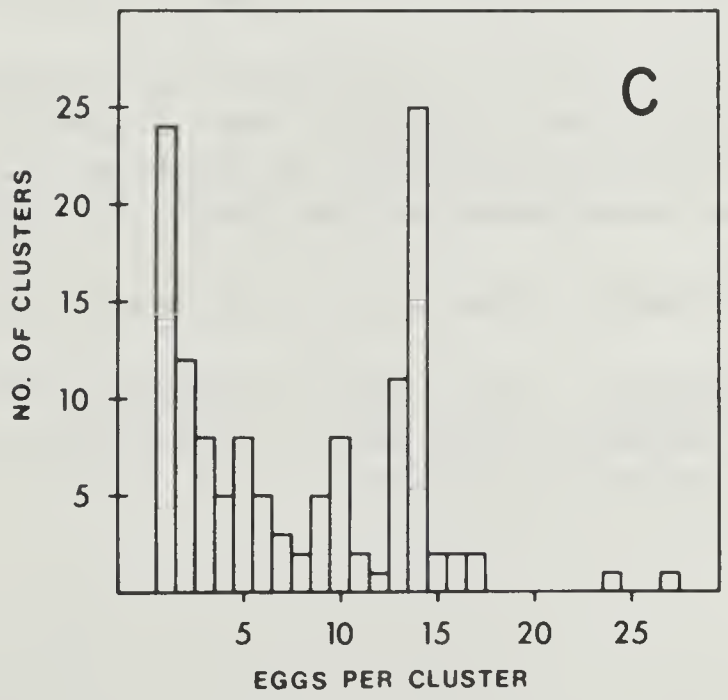

Fig. 1. Frequency distribution of egg cluster sizes of *E. t. tristigmus* at 22(A), 27(B) and 32(C)°C.

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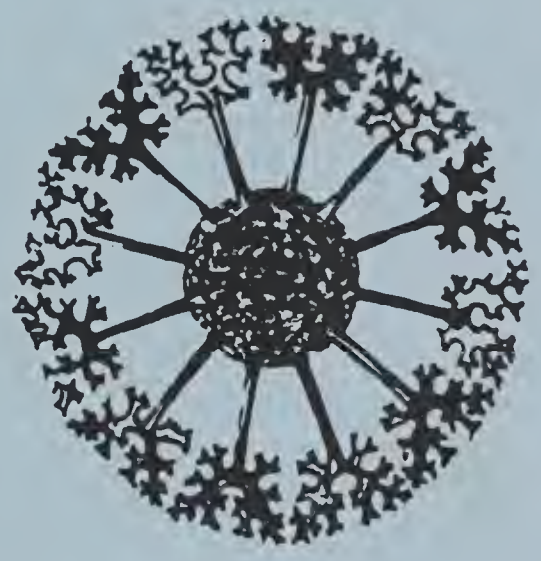

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ERRATUM

Numbers of 3 and 4 of Volume 72 mistakenly carry the date of 1980. They should instead read 1979.

NOTICE

Dr. Basil C. Hedrick has resigned as editor of the Transactions of the Illinois State Academy of Science effective with the final publication of Volume 73 (1980). Beginning with Volume 74 (1981) the editorship will be shared by Dr. Anthony Paparo and Dr. L. Richard Coulson, Southern Illinois University School of Medicine, Southern Illinois University at Carbondale, Carbondale, Illinois 62901. Please address all manuscripts and editorial correspondence to their attention.

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WHAT IS THE STAPES?

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ABSTRACT

The question of the homology of the tetrapod stapes is reexamined and the current hypothesis that it is the hyomandibula of the osteichthyan fish is rejected. The embryological evidence clearly indicates that this element is of pharyngohyal origin. The fossil evidence is also reviewed but suggests different lines of ontogeny in the several classes rather than a single coherent story.

Another discussion of the origin of auditory ossicles seems, at first glance, to be out of place, since a consensus appears to have been reached. Competent authority has said that the hyomandibula of the rhipidistian crossopterygian is the structure from which the stapes evolved. As an example of this, Thomson (1966, p. 379) remarked: ''Classical embryological and morphological studies have established beyond question the homology of the tetrapod stapes with the hyomandibular bone in fishes. This view is so well known and universally accepted that no defense or bolstering is needed...'' My excuse for this paper is that I disagree with the generally held view and believe that the opposition has not been heard.

The opposition (consisting perhaps only of myself and Frank and Smit, 1974) believes that the stapes is (or is essentially) the infrapharyngohyal and that the hyomandibula of the rhipidistian is the homolog of the extracolumella of the reptile (the stapes and extracolumella form the reptillan columella). These homologies, in my opinion, are based upon embryological facts and are consistent, in all reasonable respects, with facts derived from other approaches or from other areas of interest (i.e., jaw suspensions).

The question can be asked, ''Is it possible to sway an opinion based upon deep-rooted theory and seemingly supported by a wide range of oft-argued facts?'' It was on the assumption that eventually this *must* be accomplished otherwise this confusion will be perpetuated as in Lombard and Bolt (1979).

SOMETHING OF THE BACKGROUND

The problem of the origin of the mammalian stapes involves an understanding of the evolution of the upper part of the skeletogenous hyoid arch and the general problem of jaw suspension as well as an understanding of the comparative anatomy of the columella and stapes. Two rather distinct approaches are involved, a comparative anatomical (including development) and a paleontological. These two extremes are interconnected by a number of patterns of interpretation and hypothesis.

The current views of the homologies of these structures is, in most respects, based upon the opinions of Goodrich (1930). He pointed out (p. 450) that ''According to the modern version of Reichert's theory, the mammalian stapes derived from the reptilian columella auris, the incus from the quadrate and the malleus from the articular...'' And (p. 420) the ''...facts support the view that the hyomandibula of fishes is represented by the columella or stapes...'' Goodrich's rather lengthy and somewhat scattered discussion of the evidence also supplies much of the factual background for existing viewpoints (*see* summaries by Kingsley [1900], Westoll [1943], Shute [1956], Hotton [1960], Olson [1966], Frank and Smit [1974] and, Smit and Frank, [1979]).

Historically, several viewpoints can be identified (Figure 1). Gegenbaur (1870), Baraldi (1877), Claus (1887), Weidersheim and Parker (1890) and Gaupp (1913) suggested that the stapes (or columella) is the homolog of the osteichthian hyomandibula and this has more recently been maintained by Goodrich (1930), Stadtmuller (1936), Romer (1941, 1971), Westoll (1943), Watson (1953), Thomson (1966) and numerous others. Bertmar (1962) saw the stapes as the homolog of the columella and identified it as a fused epi-infrapharyngosuprapharyngohyal, thus adding the lateral commissure as a component. Schmalhausen (1968) assumed that the crossopterygian hyomandibula gave rise to the stapes and included in it a pharyngohyal. (He did not mention the lateral commissure, with which the hyomandibula of the fish articulates, so that it is not quite clear what his ''pharyngohyale'' is. On p. 197 he said that the stapes of the reptile is homologous with that of the urodele and ''probably represents the pharyngohyal,'' and on p. 194 he equated the pharyngohyal with ''the ventral head of the hyomandibula of crossopterygian fishes...''.) Fox (1963) believed that since the otoquadrate cartilage (post-palatine cartilage) and the columella coexisted in urodeles, and since the former was of pharyngohyal origin, the columella could not be derived from the pharyngohyal. Frank and Smit (1974) reviewed the development of this area in the crocodile and identified the stapes with the infrapharyngohyal; the remainder of the columella is identified as hyomandibula. I agree (Jollie, 1964, 1971) with this last view although I am not able to follow their entire thesis.

A part of this problem is to cut through the terminology and somehow create order in the existing nomenclatural chaos. As an initial part of this, it should be noted that the terminology of visceral arches, or their derivatives, stems from van Wijhe (1882) and was developed in part by Versluys (Ihle, et al., 1927, p. 317) and Jarvik (1954). Theory relative to the parts of the arches and their fate has been reviewed by Jollie (1968, 1971a).

The several parts of the hyoid complex which concern us (Figure 2) are, in the osteichthian fishes and thus the ancestor of the tetrapods, the laterohyal, of gill-ray origin, the infrapharyngohyal and suprapharyngohyal components of the pharyngohyal (Jarvik, 1954; Bertmar, 1962; Nelson, 1969), and the epihyal. The pharyngohyal is represented by a lateral commissure fused into the endocranium, while the epihyal is subdivided into a dorsal part, the pars hyomandibularis, and a ventral part, the pars symplecticum. The hyomandibula in these fishes is thus composed of the fused laterohyal and the pars hyomandibularis of the epihyal.

What constituted the hyomandibula of other fishes posed a real question which was never satisfactorily resolved. Jollie (1971b) pointed out that the hyomandibula of the Elasmobranchs, both sharks and rays, is formed from the epihyal without pharyngohyal additions (the pharyngohyal tissue being incorporated into the endocranium). In holocephalans the epihyal is subdivided into a dorsal, very small, ''secondary pharyngohyal'' and a ventral ''secondary'' epihyal; again the real pharyngohyal tissue is incorporated into the endocranium. Thus basically in all fishes the hyomandibula is basically epihyal in origin. What is equally important here is that the hyomandibula does not include any part of the lateral commissure, i.e., the pharyngohyal.

Another issue has been the interrelationships of the parts of the hyoid arch to the ''chorda tympani'' (internal mandibular) and hyomandibular branches of the facial nerve. This appears to be more of a red herring than anything else, since a perusal of deBeer's (1937, pp. 140-141) or Schmalhausen's (1968, p. 67, fig. 40) diagrams indicates that constancy of nerve interrelationship is less probable than the belief that the same structural units are involved in all vertebrates. Therefore, assuming the units of the hyoid arch have been used and modified in a number of ways, the phylogeny of the columella (and stapes) may be discussed.

In a comparative anatomy approach, embryological information is important. Although it is often emphasized that ontogeny does not recapitulate phylogeny, the usefulness of some embryological data in revealing evolutionary change is hard to deny. Certainly the fossil record supplies the most direct information as to the course of evolution, but an incomplete fossil record can complicate matters. Here, as in many areas of anatomy, different types of information must be integrated in order to gain a better understanding of the probable course of evolution. To attempt to review all of the relevant material would result in an overly lengthy paper. Therefore, only an outline of the total problem is given.

THE COMPARATIVE ANATOMY OF THE COLUMELLA

It is probable that the pattern of parts seen in the sarcopterygian and the actinopterygian is that of a single evolutionary line. In this line there was incorporation of the lateral commissure into the cranial wall, and the jaws were partly supported by a ''hyomandibula-symplectic'' complex. In contrast to this methyostylic type of suspension but derived from it is the autostylic suspension of the dipnoan or amphibian in which the palatoquadrate complex is articulated, sutured, or in cartilaginous continuity with the cranium. In this suspension the hyomandibula, or its representative materials, is no longer involved in jaw support. As a result of the conversion from methyostylic to autostylic, the hyoid arch elements became available for involvement in a columella transmitting vibrations from the surface of the body (or the lower jaw) to the inner ear. A transitional stage in the origin of the columella is suggested by the hyomandibula-lateral commissure of the dipnoan, *Neoceratodus*.

The development of the upper end of the hyoid arch in *Neoceratodus* has been studied by Schmalhausen (1923). Edgeworth (1935), Bertmar (1959, 1963, 1966), and Fox (1963). Bertmar's accounts clearly indicate the occurrence of a lateral commissure and an epihyal (Fig. 3) in both *Neoceratodus* and the amphibian. Fox (1963) denied the possibility of a pharyngohyal contribution to the urodele columella but recognized the post-palatine cartilage, a process extending outward from the cranial base underlying the foramen of the VII nerve, as of pharyngohyal origin. Actually Fox's work supports the present thesis in that the lateral commissure, which undergoes reduction with development, could easily be reduced to the two components seen in amphibia, the stapes and the otoquadrate cartilage. The lack of apparent connection between the blastematic hyoid arch and the stapes in amphibians can be explained as part of the highly modified pattern of development. Nowhere in my argument is it held that the lateral commissure forms only the stapes; further, it is a necessary part of this argument that the lateral commissure be viewed as greatly reduced in extent if it is represented, even in part, by the stapes. I agree entirely with Bertmar's (1962) homologizing of anlagen in *Neoceratodus* and urodele, but question his definition of stapes. Had he said columella, no question would have arisen. The problem then comes down to what is the columella and is the stapes a part of it? The best source of materials to answer this appears to be reptiles.

What appears to be simple stage of the columellar apparatus is seen in some lizards (Versluys, 1898). Unfortunately there is much variation in this structure so that selection of a ''type'' is out of the question. Weber and Werner (1970) suggest there are three basic types. Particularly confusing is the relationship of the ceratohyal to the columella. Everyone (including myself) agrees with Goodrich (1930, p. 452) that embryologically ''The columella is developed from the dorsal end of the hyoid arch.'' However, what parts of this arch complex are involved is a matter of controversy (*see* comments and terminology of Olson, 1966).

The development of the hyoid arch in amniotes indicates rather clearly what has happened to the hyoid arch (Figure 4). The initial stage is reported by Kingsley (1900, fig. 2) for the lizard, Frank and Smit (1974) for the crocodilian, Engelbrecht (1958) and Smit and Frank (1979), for the bird (also Crompton, 1953; Muller, 1964; Goldschmid, 1972), and Kingsley (1900, fig. 6a) or Ihle, et al. (1927, fig. 445) for the mammal. In each case the hyoid arch extends up, turns inward at a sharp angle, and inserts into the vestibular fenestra (or is in blastematic continuity with the otic capsule). At a very early stage a small tympanic process is evident which expands outward. With development it carries with it the site of attachment of the ceratohyal in the lizard (Figure 5). The dorsal process differentiates next and extends upward (or posteriorly) to the paroccipital process. It lies lateral to the root of the facial nerve and the lateral head vein. The internal process marks the original area of connection with the ceratohyal; in some cases it develops after the ceratohyal has shifted laterally on to the tympanic process. This shift is often indicated by a sharp kink in the ceratohyal.

The adult columella (Figure 6) consists of a number of processes. The columella shaft is formed medially of the stapes, the foot plate of which fits into the vestibular foramen of the otic capsule. Laterally the columella extends outward to the tympanic membrane by way of the extracolumella, much of which can be viewed as tympanic process. The tympanic process (whatever its shape and

degree of development) is generally equated to the opercular process of the hyomandibula. Usually there are ''processes'' (dorsal and ventral) in the tympanic membrane from the outer end of the extracolumella.

The dorsal process may represent the laterohyal, the dorsal head of the hyomandibula; it forms dorsally the intercalare. The end of the tympanic process may connect dorsally with the intercalare forming a fenestra between it and the dorsal process. The dorsal process may be perforated by a small foramen (Huxley's foramen).

From the medial end of the extracolumella an internal process extends down (or anteriorly) toward the quadrate. In appearance this would represent the main axis of the epihyal. The long internal process of the alligator or bird involves the inclusion of some of the ceratohyal.

The remainder of the hyoid arch now begins with the ceratohyal element which may retain connection with the epihyal region of the columella, as is seen in *Sphenodon* or the young stages of many lizards; or secondarily it may acquire an attachment to the paroccipital process through ligamentous derivatives of the laterohyal.

In the reptile the columella has at least two centers of chondrification, one for the stapes portion and one for the extracolumella (although the latter may fragment into two or more centers). There is only a single ossification center, and this is stapedial.

The columella in the amphibian (plectrum of Gaupp, 1893) is not as well understood as in the reptile, the more so because of the many confused accounts (for example, Goodrich, 1930, pp. 478-485). A tympanic membrane is found in most of the Anura, as well as a columella supported in a middle ear cavity. In addition there is an operculum. In salamanders and the apodans, the tympanic membrane and middle ear cavity are lacking and the stapes generally articulates with the palatoquadrate (or quadrate in apodans) or the overlying squamosal. The articulation with the palatoquadrate or squamosal may represent an extension of ossification from the stapes into the extracolumella. This connection may be only ligamentous, or lacking. ''According to Marcus, the rudiment of the columella or *Hypogeophis* is in the early blastematous stage continous with the remainder of the hyoid arch. This is an important observation, since it is the only case of such continuity described in the Amphibian,. . .'' (Goodrich, 1920, p. 482).

An operculum is present in some salamanders and indeed appears to replace the rudimentary stapes as a sound-conducting mechanism in *Triton* and *Notophthalmus (Dimictylus)* (Kingsbury and Reed, 1909). An operculum is lacking in the Apoda (contrary to Goodrich, 1930, p. 482, fig. 508), and in some salamanders (*Necturus, Cryptobranchus, Siren, Amphiuma).*

The ontogenetic evidence concerning the amphibian columella is controversial. Much of the confusion is traceable to Reed (1920) who contradicted some of the results of Kingsbury and Reed (1909). I believe that the earlier report is the more accurate. The discussion as to whether the stapes is of hyoid or otic wall origin (Parker, 1871, 1877) is another example of difference of opinion. If we presume that the pharyngohyal primitively fused to the otic capsule (Jollie, 1971a), then the apparent origin of the stapes either from a separate hyoid blastema or from the ''otic wall'' would be expected as opposite extremes of a single developmental potential. If the pharyngohyal formed the style of the stapes, the footplate could have arisen either as an expansion of the end of the style, overlying the otic capsule wall (and by resorbtion of the otic capsule wall it came to lie in the fenestra vestibulae), or the style, fused to the otic wall, could have acquired the footplate (and fenestra vestibulae) by excision from the capsule wall. If the fenestra vestibulae was already present in the fish, as a vestibular fontanelle, then a third explanation is in order. This would be that the footplate arose by expansion of the end of the pharyngohyal into the vestibular fontanelle. (The form of the vestibular fontanelle, as it occurs in crossopterygians, would not support this.) Ontogeny as currently understood (*see* Kingsbury and Reed, 1909; Srinivasachar, 1962) does not give preference to either of the first two schemes (resorbtion and excision), while the third is not known as an ontogenetic process. Since what develops, more or less directly, in the embryo is a functional conducting system, the possible deletion of an initial phylogenetic stage is understandable.

The problem of the operculum should be examined. Parsons and Williams (1963, p. 30) say that ''there is in at least two of the three modern amphibian orders a second sound-transmitting bone or cartilage, the operculum, a skeletal element posterior to the footplate of the stapes in the

fenestra ovalis.'' Further, they suggest that even in the Apoda (the third group) the operculum ''is fused with the hyoid portion of the columella.'' These statements establish a view that the operculum is present in the Apoda, where it appears as the footplate, and is a ''skeletal element'' (and, therefore, of systematic importance and constancy—i.e., not just a secondary functional element seen in certain amphibians utilizing a pectoral limb conduction mechanism). They also suggest that it is at least sometimes bony, as in the Apoda; and a part of the ear capsule wall is usually involved in its formation.

The story of the operculum has been twisted in a number of directions. Eaton (1959, pp. 164, 165) suggested that since only *Necturus* and *Proteus* of all the amphibians have a distinct opisthotic but no operculum, ''it may be that the opisthotic becomes the operculum in frogs.'' This correspondence of operculum and opisthotic has been picked up and is now well established among morphologists, even though there is no evidence for such a homology. In the bull frog there is an opisthotic ossification center which almost immediately joins with the exoccipital (Jollie, 1962, p. 83; Kemp and Hoyt, 1969, p. 420, in *Rana pipiens),* while the operculum is a separate cartilaginous nodule (calcified) embedded in the connective tissue overlying a reduced fenestra vestibulae. It is evident that in most living amphibians (the Lissamphibians) the fusion of opisthotic and exoccipital occurs early, and to all appearences it is the exoccipital which extends into the posterior part of the otic capsule. Thus, there is no evidence of the opisthotic being involved in the operculum. Further, the operculum is seldom, or never, ossified—there is a small calcified or bony area in *Ambystoma* (personal observation).

As described by Kingsbury and Reed (1909) the operculum is cut out of the otic capsule wall posterior to the columella and the original fenestra vestibulae. This event occurs by the time of metamorphosis or not at all. As a late event in the life history of the amphibian it is not likely that it was a structure invented by and characteristic of the ancestor of the Lissamphibia; certainly it is not a basic feature of tetrapods in general. The suggestion that it represents a separate foot plate must also be rejected.

Discussion of an operculum in apodans appears to be a result of confusion (certainly those figured by Olson, 1966, figs. 5, 6, are not identifiable as Apodans). Goodrich (1930, fig. 508) labelled as the operculum of *Ichthyophis* a ventroposterior process of the stapes. All adult apodans agree in having a massive stapes with a large irregular footplate fitted into the otic capsule wall and articulating with the quadrate by a lateroanterior ''style.'' They are not unlike urodeles in general.

The search for an operculum in fossil forms is probably a waste of time, since this structure characteristically remains cartilaginous; i.e., it is not a primary skeletal feature but rather a functional one related to the attachment of muscles on the otic capsule (Monath, 1965).

The point has been raised as to the occurrence of an extracolumella in any amphibian. The evidence (summarized in part by deBeer, 1937) suggests that one is present in all amphibians and certainly in the Anura. The blastema of the columella is generally two-parted and chondrifies in two parts (Schmalhausen, 1968, p. 194). The external part is in contact with the tympanum, it is connected, by what appears to be the laterohyal, with the paroccipital process (or an adjacent part of the otic capsule in some toads) and for a time by a band of tissue with the end of the ceratohyal which is now attached to the ventroanterolateral angle of the otic capsule below the level of the stapes (Baldauf, 1955, 1959; Sedra and Michael, 1959). The Anuran appears to resemble the reptile in some respects but lacks dorsal and internal processes. The extracolumellar portion may be fused with the palatoquadrate in salamanders and apodans; certainly it is not distinct. The view that the Anuran columella has ''partes interna,'' ''media'' and ''externa plectri'' (Sedra and Michael, 1959) is rejected on the grounds that the observations are not convincing, nor does the use of these terms seem justified.

A complete hyoid arch blastemic strand has been observed in a few species of urodeles and in apodans, but this condition is quickly altered in the direction of the adult structures. Thus, as in some other areas of their anatomy, the amphibia appear to be more modified than other tetrapods (Evans, 1944; Jollie, 1962). The occurrence of an otic operculum also supports the assertion that the amphibians are more modified than the reptile. Both the Amphibia and the Reptilia species specialized for burrowing agree in the loss of the tympanum, middle ear cavity and eustachian tube

(salamanders and apodans among the Amphibia, amphisbaenids and snakes among the reptiles). Some burrowing toads (*Pelobates)* and even aquatic types (*(Bombina)* have lost the middle ear space and retain only a narrow eustachian tube. Even the eustachian tube is lacking in *Ascaphus,* a frog, living in mountain brooks.

Thus the columella of at least two of the three groups of libing amphibians consists of parts which can be equated with the stapes and extracolumella of the reptile. The columella may not have an evident footplate but the operculum, when it is present, represents an excised piece of the capsule wall related to muscle insertions serving for sound conduction. In terms of development the anuran differs from the reptile only in having a more direct development toward the adult condition.

The mammalian system was derived from a columellar one not particularly like that of a lizard. The approximate situation of the stapes, quadrate and lower jaw is known in a number of therapsid reptiles, assumed to be the group from which the mammals evolved. Romer (1970) has described the stapes and jaw articulation of a small cynodont *Probainognathus.* In this and other cynodonts the stapes articulated laterally with the quadrate; there is no evidence of an extracolumella (cartilaginous?). Further, the quadratojugal, prominent in pelycosaurs, is either free (*Thrinaxodon,* Estes, 1961; Hopson, 1966) or fused with the quadrate (*Probainognathus).* Reduction in the size of the quadrate is accompanied in Probainognathus by development of an articulation of the dentary with the squamosal lateral to the quadrate (also in *Diarthrognathus,* Crompton, 1963).

Barry (1968) described an attachment of the assumed ceratohyal to the stapes (suggestive of Fig. 4i) in the anomodont therapsid *Lystrosaurus,* suggestive of the embryological stage for man figured by Broman (Fig. 4h). What is not shown in the mammal figure is the quadrate which lies anterior to the distal end of the stapes and in articulation with it, presumably by way of its internal process. This difference between fossil and embryological stories is disturbing and calls for explanation.

Whereas in fishes the pharyngohyal tissue is fused to the endocranium, we see a progressive separation in the amniotes culminating in the mammals in which the inner dorsal end of the hyoid arch is not fused to the cranium. The development of the incus is also peculiar in mammals where its jaw articulation function is lost. This bone has a long crus going inward and back to articulate with the stapes (Fuchs suggested that the crus longum was a separate entity from the quadrate—perhaps the internal process of the extracolumella [deBeer, 1937, p. 413]) and a short crus extending up and back to articulate with the otic capsule (i.e., paroccipital process). The development of the incus is a direct one with little evidence of its evolution. There is a question as to what became of the quadratojugal.

From the developmental information not much of the extracolumella is retained in the mammal: ''The mammalian stapes would, then, represent the proximal region of the columella without its extra-stapedial bar and insertion in the tympanum'' (Goodrich, 1930, p. 459). It appears that the intercalare part of the dorsal process forms the region of attachment of the hyoid arch to the cranium. The styloid process-intercalare attachment of the ceratohyal appears to be a displaced attachment as in many reptiles.

Spence's cartilage, seen in the cat, may represent the ''body'' of the extracolumella. Paaw's cartilage as a nodule in the insertion tendon of the stapedial muscle may be only a neomorph without significance. Discussion as to possible homology of these cartilages is pointless at this time. The main question is whether the perforate stapes of the mammals is fairly homologous to that of the reptile and this seems to be the case.

The ontogenetic history of the upper part of the hyoid arch in the different classes supports the supposition that in the beginning there was a columella composed of an inner bony stapes and an outer cartilaginous extracolumella. The inner stapes element can best be identified as a remnant of the pharyngohyal component of the hyoid arch. The generally accepted view appears to discount or garble the embryological information and to find much of its basis in the paleontological evidence. Whether the typamic processes and the tympanums of the several classes are homologous, as discussed by Lombard and Bolt (1979), is not of concern here.

THE PALEONTOLOGICAL VIEW

The paleontological view can be introduced by way of Hotton's (1960) account. Hotton bluntly stated that the "tetrapod stapes was derived from the hyomandibular bone of the rhipidistian fishes," and his figure (Figure 7) showed how this was done. His description stated that the lateral commissure disappeared and the stapes (hyomandibula) came to articulate directly with the otic capsule above and below the lateral head vein. Important here is the equation generally of the stapes with the columella (Watson, 1953, p. 163). (I shall continue to separate the two structures although recognizing the probability of extension of ossification from the stapes into the extracolumella in Pelycosaurs.)

The first stage of columellar history described by Hotton was that represented by the anthracosaur amphibian. In this, the cranial roof is said to be much like that of the rhipidistian and is separated in part from the cheek by an otic notch, left perhaps by replacement of the operculum by a tympanic membrane. The columella was a horizontally directed bone without an evident dorsal process. Actually the columella of the anthracosaur is not known, but may be thought to resemble that of the temnospondyle (Romer described the columella of *Greererpeton,* lower Carboniferous, at the 1972 national meeting of the Society of Vertebrate Palecontology; *see* also Thomson, 1966, fig. 5). Hotton pointed out that "Future discoveries may reveal primitive anthracosaurs with massive stapes, but the fact that none have been found to date suggests that the anthracosaur stapes must have been a smaller, more easily lost ossicle than that of other labyrinthodonts."

Hotton assumed that the anthracosaur type led to a second stage represented by the Pelecosaur (synapsid) reptile *Dimetrodon* (Fig. 8D). One is led to believe that the pelecosaur stapes represents only a slightly modified hyomandibula in terms of its form, orientation and relationship with the chorda tympani nerve. ("As first pointed out by Sushkin (1927) the position of the hyomandibular in the crossopterygian fish is very similar to that of its homolgue the stapes in early reptiles..." Panchen, 1964, p. 629.

From the pelecosaur stage, Hotton passed to the captorhinomorph (Fig. 2C) in which the "stapes" is said to have returned to a small size and a horizontal position.

The sequence of stages described by Hotton is peculiar, since the captorhinomorph and anthracosaur are more alike, yet are separated by the interposition of a pelycosaur. If a comparison of roof structure with the assumed "ancestral" rhipidistian has any meaning, and this aggreement would have to be a general sort, then *Captorhinus* appears less modified and *Dimetrodon* more modified in terms of its cranial roof and snyapsid cheek. Yet the assumed comparison of stapedial structure is the reverse of this. If the symouriamorph type, as seen in *Seymouria* (Fig. 8B), or that hypothesized by Thomson (1966, Fig. 5) for the anthracosaur *Palaeogyrinus,* is close to the ancestral cotylosaur, then the horizontally oriented columella is primitive and the oblique position and enormous size seen in *Dimetrodon* are modifications. Thus the resemblance of the *Dimetrodon* columella to the fish hyomandibula is meaningless—a form convergence not involving the same selective or shaping forces.

The peculiar columella of the pelycosaur is remarkable in one feature that should not pass unnoticed. I believe it may represent an extension of the stapedial ossification into an expanded extracolumella (hyomandibula), the function of which is unknown (*see* Hotton, 1959). Extension of ossification into the extracolumella is possible in other fossil forms where the tympanic process is an integral part of what must be presumed to be basically the stapes.

The weakness of the paleontological approach is the assumption that one must start with the rhipidistian hyomandibula. One might more easily start with a situation like that seen in the dipnoan, in which the hyomandibula is greatly reduced in size and an "autostylic jaw suspension" has been developed. It is safe to say that the rhipidistians, as we know them, were not directly ancestral to the amphibian (nor were the dipnoans). The hyomandibular-lateral commissure situation of the dipnoan (as seen in *Neoceratodus)* could lead to the columellar apparatus of living tetrapods with a primitive, horizontal, stylus-like stapes.

Yet another idea need be entered here. Parrington (1956) and others have been led by the conflicting evidence to the conclusion that the labyrinthodont could not have been ancestral to the

amniotes. The nature and origin of the columella of the frog and the modified ontogenetic story in living amphibians generally suggests that the ear structure of amphibians, fossil and living, differs basically from that of the amniotes. These differences correlate with the fact that the quadrate of the amniote articulates with the otic capsule at the paroccipital process, while that of the amphibian is an ossification restricted to the area of articulation with the lower jaw, in a larger palatoquadrate cartilage. The amphibian quadrate is supported by dermal bones, the pterygoid and squamosal, which attach to the cranium. The biphyletic or polyphyletic origin of tetrapods is not a new idea and has been suggested in terms of the origin of limbs as well as in cranial structure (Säve-Söderbergh, Holmgren, Jarvik). My opinion is that the tetrapods are monophyletic but that the stem amphibian and reptile lines diverged almost immediately.

Fossil evidence, while not convincing in terms of the origin of the parts of the columella, does indicate something of the evolutionary history of the mammalian ear. The mammalian middle ear is of special interest because two distinct functional stages have existed, one replacing the other. The middle ear system of the synapsid reptile was probably something like that of the living reptile. The extent of the extracolumella can only be conjectured. This type of conduction system was gradually replaced as a result of changes in jaw function and in articulation. The bones of the posterior end of the jaw became much reduced in size and ventromedially directed; the dentary came to articulate with the squamosal lateral to the quadrate-articular joint. While these events were occurring, the original tympanum and the tympanic cavity were expanded into the region of the articular bone (as described by Westoll, 1943, or Hopson, 1966). The ventromedial and anteriorly directed retroarticular process (the manubrial process) of the articular now extended out in the tympanic membrane.

The direct embryological development of the mammalian middle ear cavity does not in itself contribute to this phylogeny, but Shute's (1956) theory is one of the explanations of the origin of the mammalian middle ear both in terms of its development and in terms of its functioning during the conversion period. Hopson (1966) has argued on the basis of depressor muscle systems that the mammalian middle ear conductive mechanism arose at least twice. The main point is that "the retroarticular process (the malleus) could not be taken into the ear until the reptilian depressor mandibulae was lost...(and)...this muscle could not be lost until its function was...taken over by a...mammalian type of jaw-opening muscle. Since there were at least two quite independent origins of mammalian depressor muscles, it follows that there were also at least two independent origins of the mammalian middle ear mechanism."

This argument assumes that there is only one muscle mechanism involved at any one time in depression of the mandible. An evolutionary change demands that this cannot be the case, since replacement of one muscular mechanism by another requires a period of overlapping cooperative function. It is not inconceivable that the present depressor of the mandible in *Ornithorhynchus* is one alternative modification of the original jaw-opening complex.

There is some doubt as to whether the ear remained "functional" during this transition from reptile to mammal. One view is that the original columellar system was totally abandoned; the stapes articulating with the quadrate, the tympanic membrane was lost and the tympanic cavity was reduced or lost. Later the new system developed with its own new tympanic membrane (Watson). Again the idea of loss of one system and later invention of a replacement one assumes greater evolutionary plasticity than I want to grant. I prefer the idea of gradual transition from one system to the other (as does Hopson, 1966).

SUMMARY

The problem as examined in this paper comes down to whether the stapes is the homologue of the fish hyomandibula (i.e., ephihyal) or of the infrapharyngohyal part of the lateral commissure. To homologize it with the hyomandibula (as has been done) requires that the lateral commissure be dismissed as having disappeared. Disappearance of this basic tissue is possible, but its uniform appearance in fishes and in (some) developing amphibians suggests it has not, in fact, disappeared. If one assumes that at least some remnant of the lateral commissure is present, then it can be

homologized with the stapes. The position and relationships of the stapes, below the lateral head vein and hyomandibular nerve suggest a part of the lateral commissure, not the hyomandibula.

The original fused condition of the lateral commissure with the endocranium is important in understanding the close relationship between otic capsule and stapes. Fusion occurs in some stages in Amphibia; such fusion would be quite unlikely with a hyomandibula. If the stapes is part of the lateral commissure, then the extracolumella of lower vertebrates can represent the hyomandibula.

The strongest piece of evidence in this argument is the developmental picture in *Neoceratodus*. There appears to be both a rudimentary hyomandibula and a modified (reduced) lateral commissure—reduced to a stylus-like structure fused with the otic capsule. Using the evidence from *Neoceratodus* one can visualize a number of stages from a jaw supporting hyomandibula to an autostylic suspension with the lateral commissure reduced to a stapes and the hyomandibula transformed to an extracolumella.

The second most important piece of evidence in this argument is the unlikely anatomical possibility of converting a crossopterygian fish to an amphibian. One sees in the crossopterygian a jaw mechanism involving a large hyomandibula (and symplectic?). There is a separate lateral commissure fused with the endocranium which serves as the area of articulation for the hyomandibula. This jaw apparatus of the crossopterygian, coupled with the hinged endocranium, suggests an evolved (not primitive) mechanism which would not be abandoned for an autostylic suspension, along with loss of cranial kinesis. The hinged endocranium strikes me as an adaptation developed only in the crossopterygians—a part of their predatory way of life. It is unlikely that evolution, headed in one direction with a particular kind of cranial kinesis, would reverse itself. Further, I believe that the several jaw mechanisms seen in early Devonian fishes all represent a single radiation—that of the amphibians was essentially a part of this, being more like the dipnoan than the crossoptergian.

The paleontological record tells us little relative to the origin of the stapes. When first found in the fossil record, the amphibian is a dorsoventrally flattened form, obviously benthic in habit, while the crossopterygian is usually oval in cross section, deeper dorsoventrally than laterally, and with typical fish adaptations for swimming. Like *Polypterus* the crossopterygian may have spent much time on the bottom, but it was still a swimmer, not a creeper.

The earliest known amphibians are already highly modified creatures as compared with either crossopterygian or dipnoan; they are diverse in structure (two or more distinct lines of cranial anatomy) and many differences in details (rib structure of ichthyostegids. The probability is good that the larger amphibians known from the fossils are not the direct line to later amphibians and reptiles and, therefore, may not tell us too much about the columella and its evolution. Certainly this last comment seems to apply to the known columellas of early synapsid reptiles (the pelycosaurs). Recognizing the possibility that in some of the fossil forms (and some living amphibians) the ossification of the stapes may have extended well out into the extracolumella, it is the opinion of this author that normally the stapes (infrapraryngohyal) and extracolumella (hyomandibula) are separate and this was the situation in the phylogenetic line that gave rise to the mammals and to the mammalian stapes.

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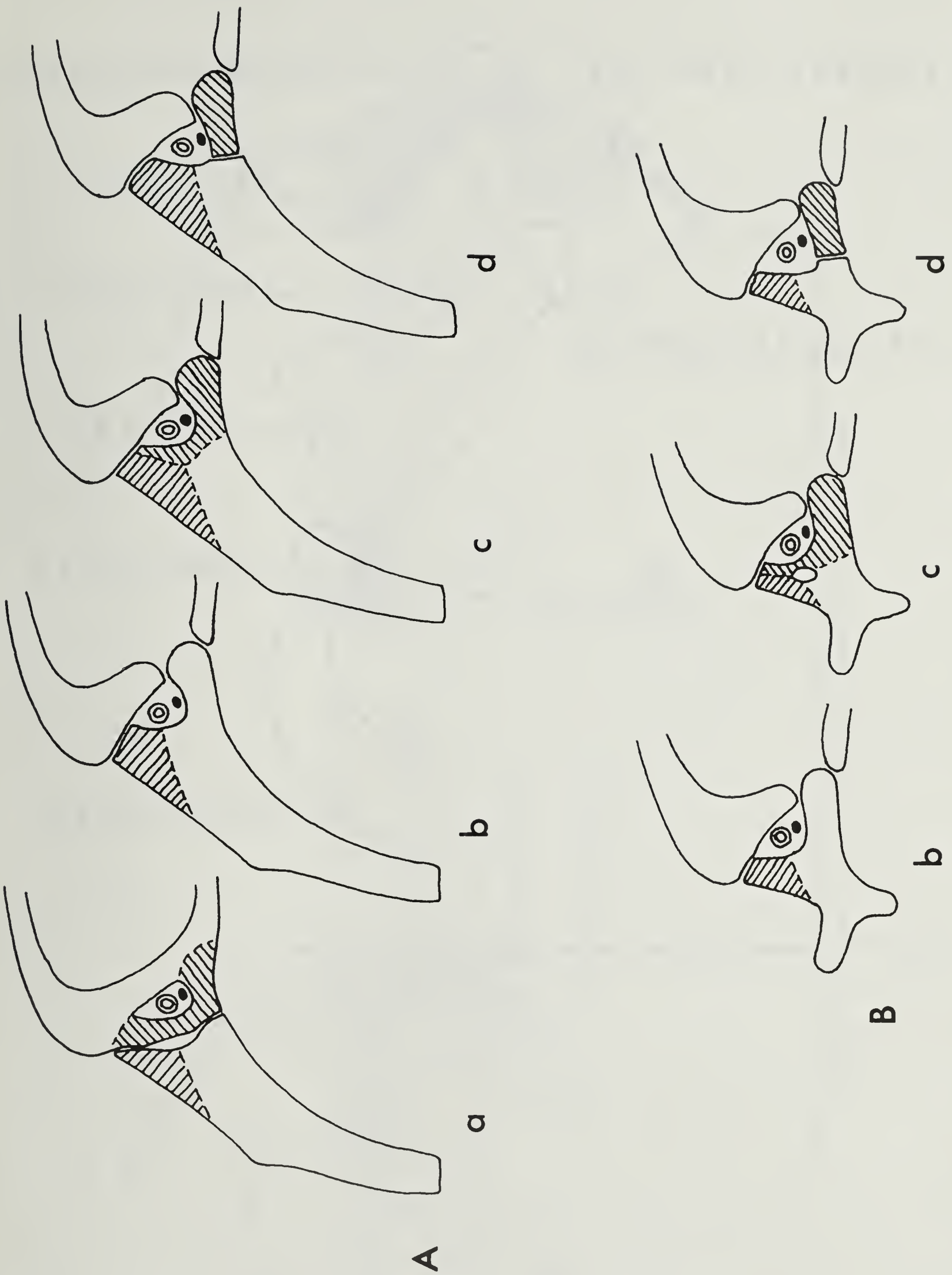


Figure 1. Diagrams of theories of homology. A. Drawn as if the crossopterygian hyomandibula were converted into the columella; B. As if hyomandibula were reduced to rudiment as in *Neoceratodus* before conversion. a. primitive condition with both hyomandibula and lateral commissure (laterohyal and lateral commissure oppositely crosshatched); b. theory in which hyomandibula is columella ([5]stapes), no lateral commissure present; c. theory in which pharyngohyal is part of columella ([5]stapes); d. theory in which hyomandibula is extracolumella and part of lateral commissure is the stapes.

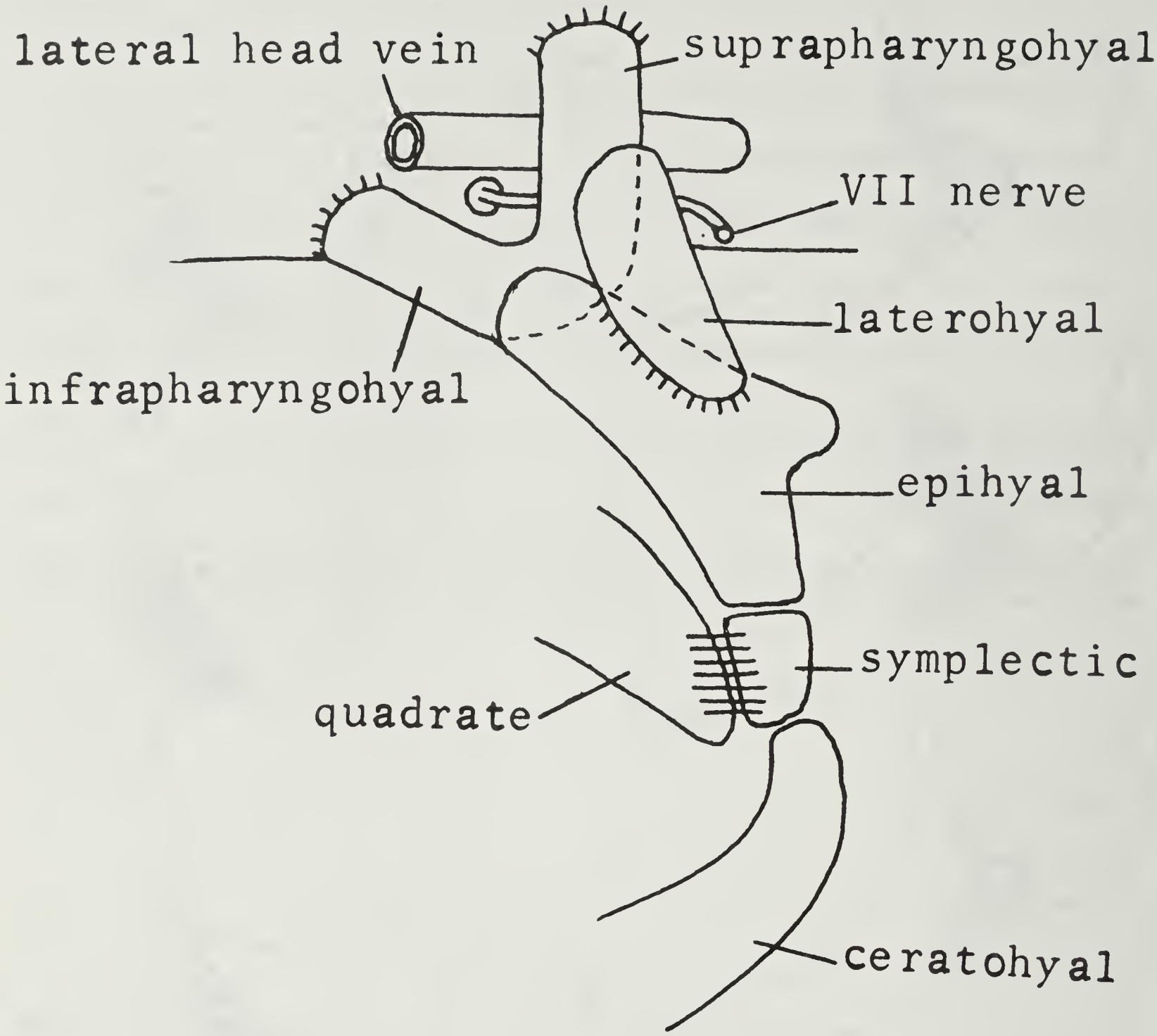
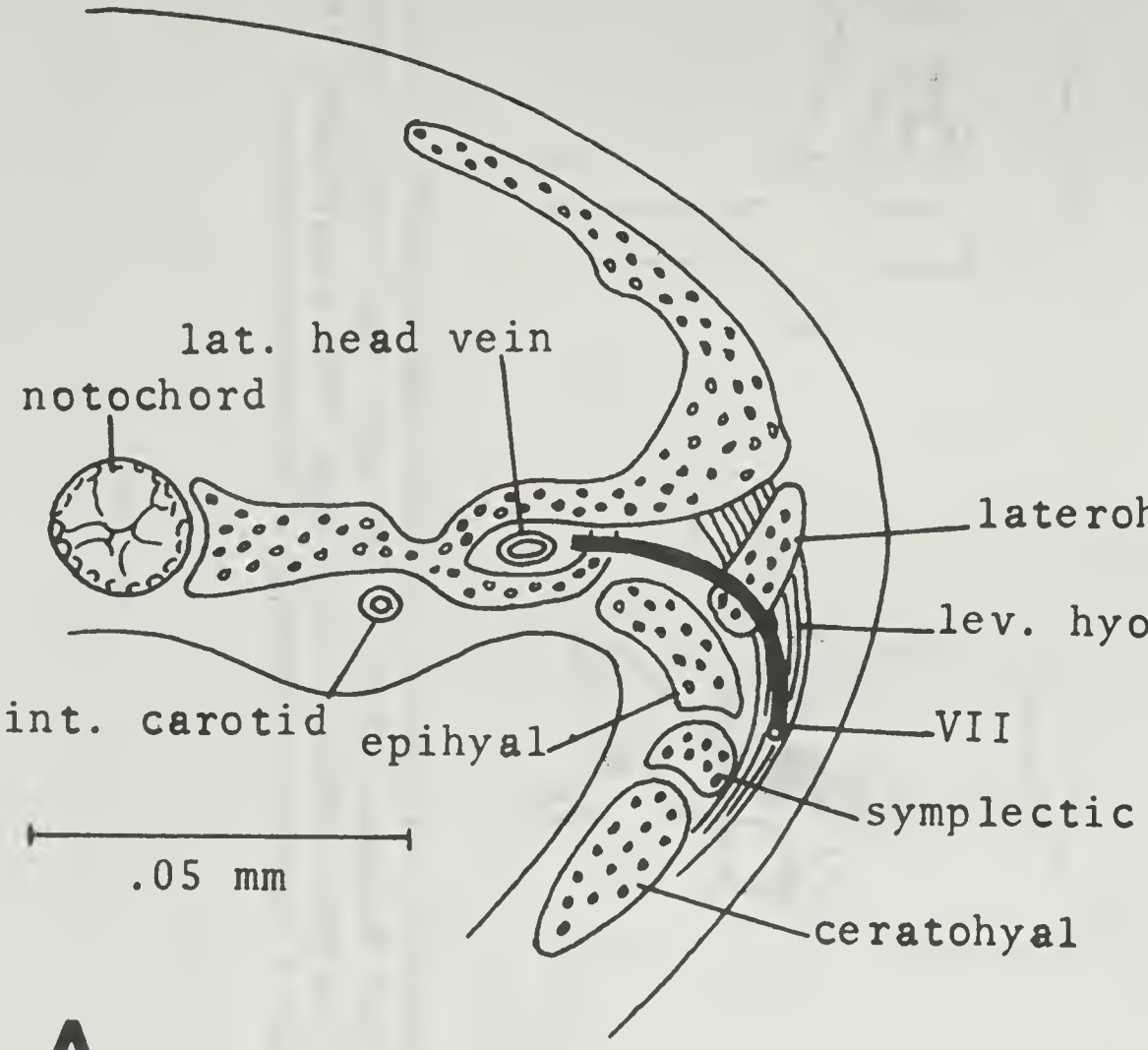


Figure 2. The several components of the dorsal end of the hyoid arch.



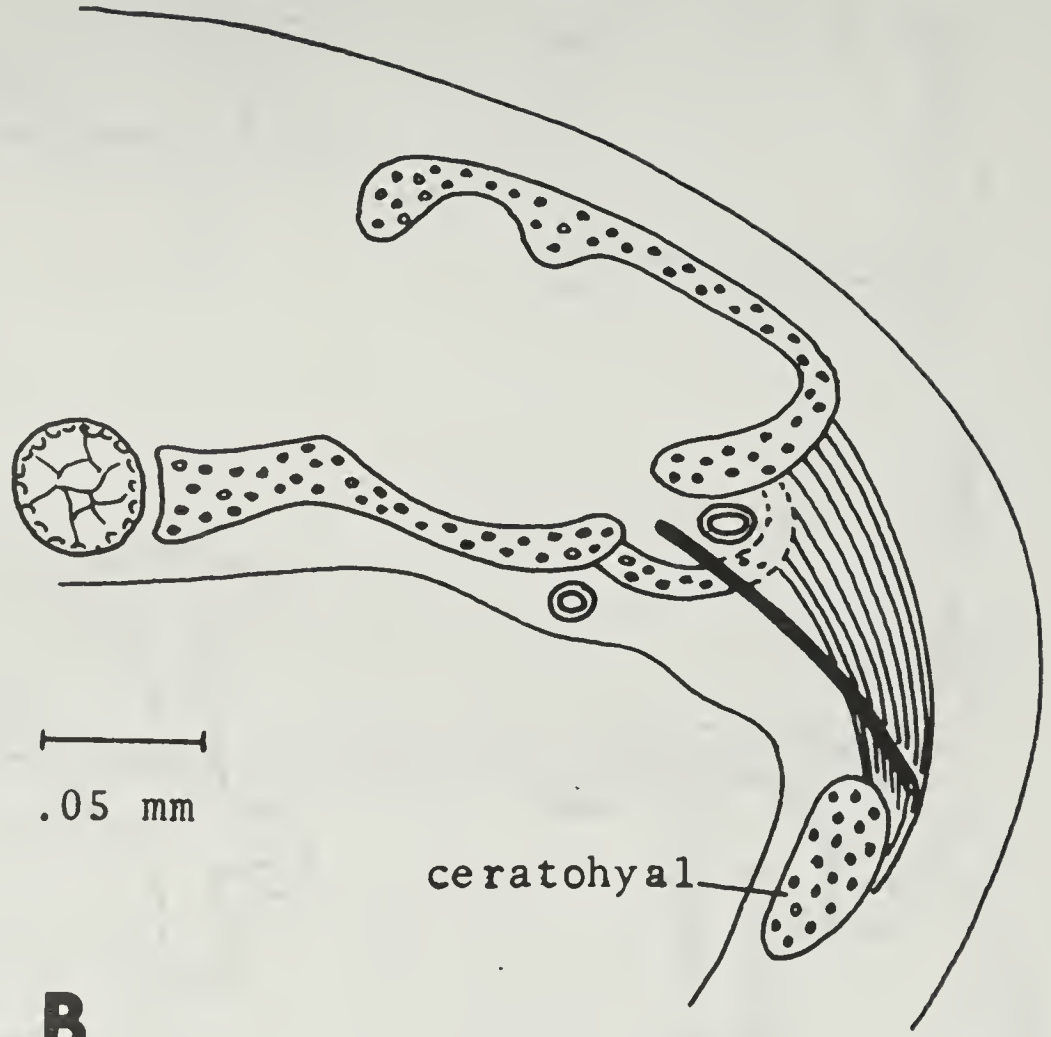


Figure 3. Cross sections of *Neoceratodus* and a salamander (*Hynobius*)which suggest at least partial correspondence in terms of the lateral commissure (after Bertmar, 1962).

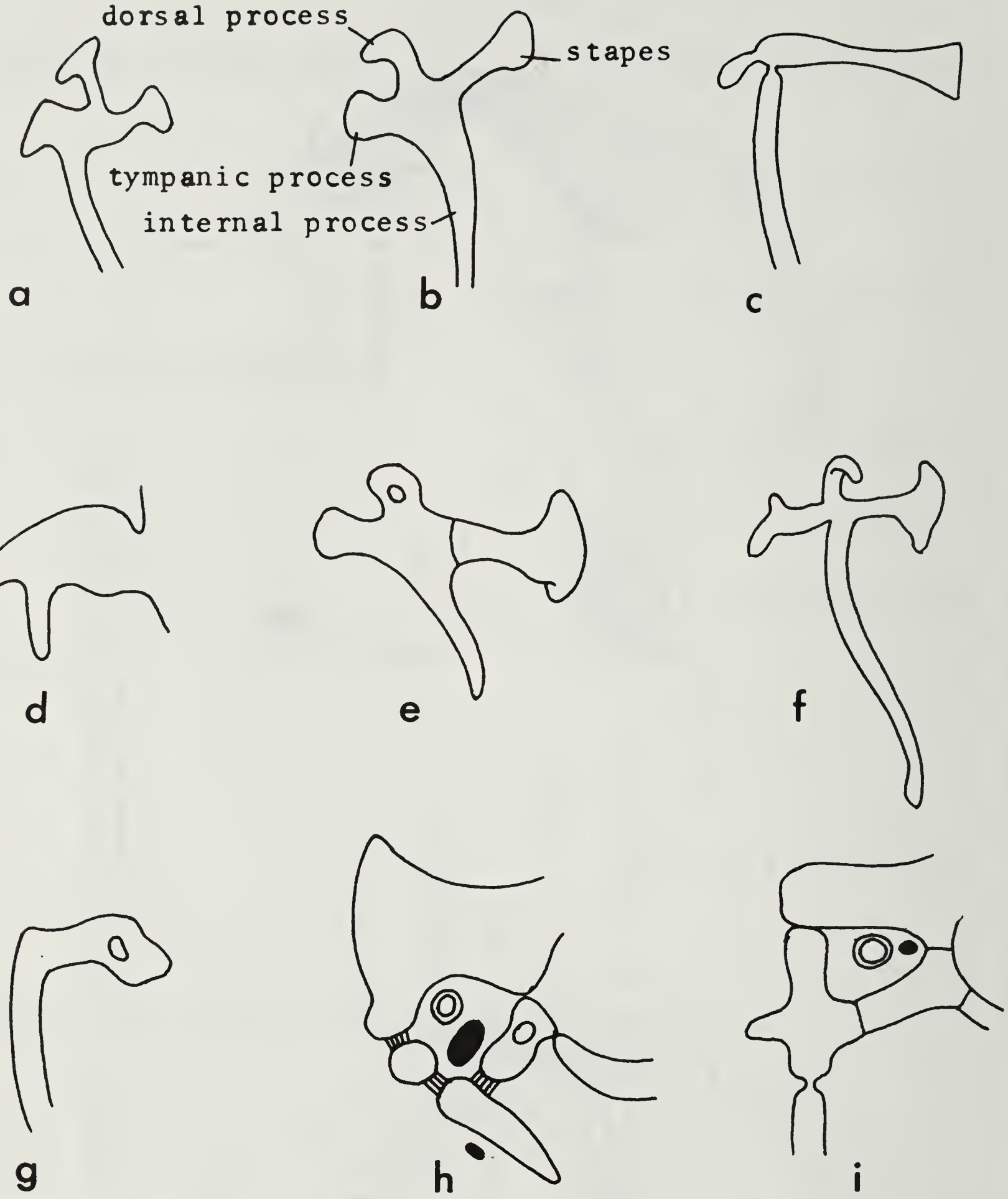


Figure 4. Early stages of the hyoid arch. a. *Platydactylus* embryo (Versluys, 1936); b. *Alligator* (Kingsley, 1900); c. lizard (Kingsley, 1900); d. very early stage of bird, *Pyromelana* (Engelbracht, 1958); e. *Rhea* (Miller, 1963); f. *Struthio* (Lang, 1956); g. pig (Kingsley, 1900); h. human (Ihle et al, 1927); i. hypothetical subdivision of dorsal end of hyoid arch.

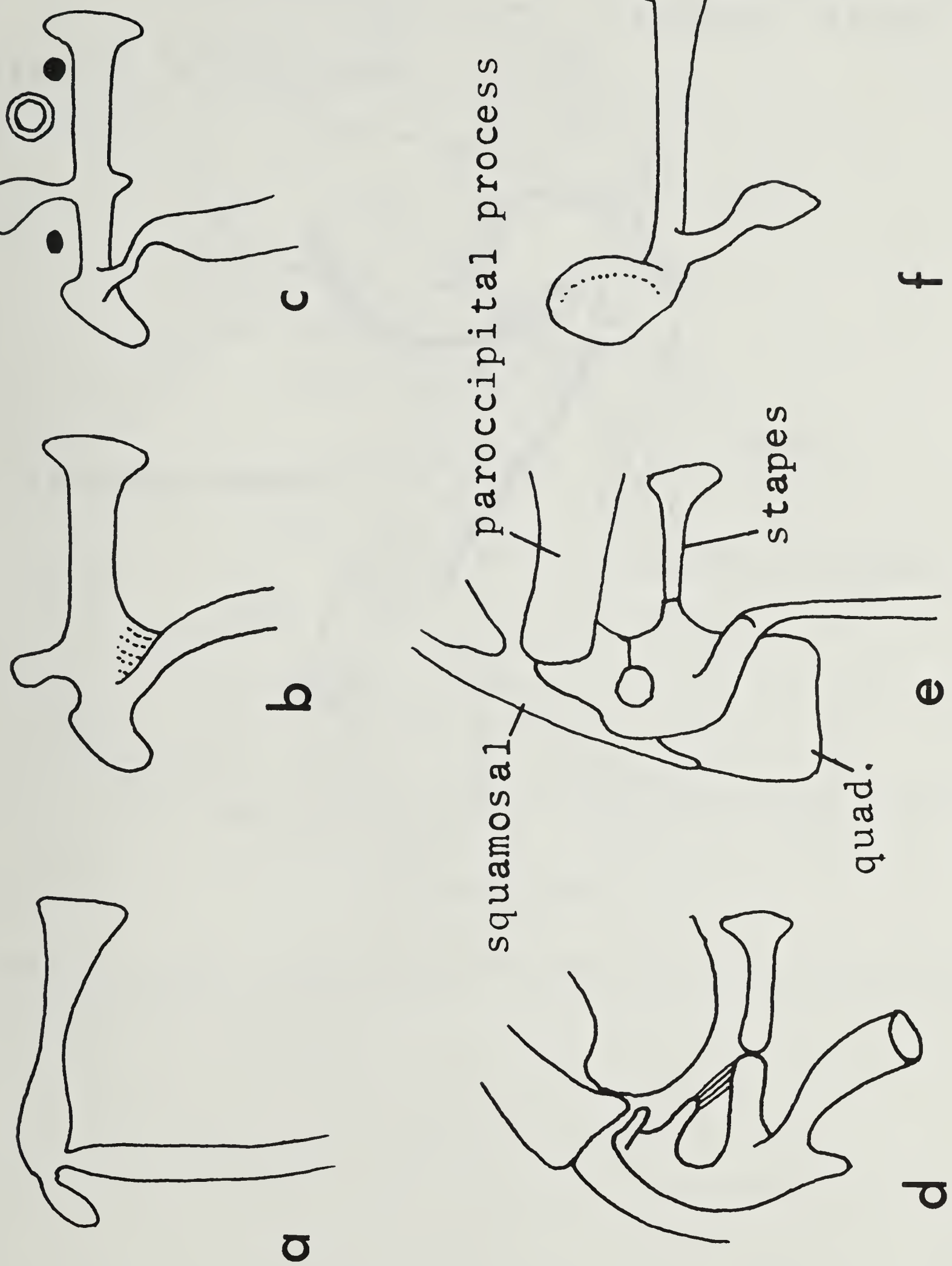


Figure 5. Some stages in the shift of the ceratohyal connections. An alternate route not shown would be up the dorsal process. a,b,c three stages of lizard (a and b after Kingsley, 1900, c after Goodrich, 1930), black circles equal VII nerve, open circle is lateral head vein; d, e developing *Sphenodon* (after Versluys, 1936); f. *Chelone* (after Fuchs, 1915).

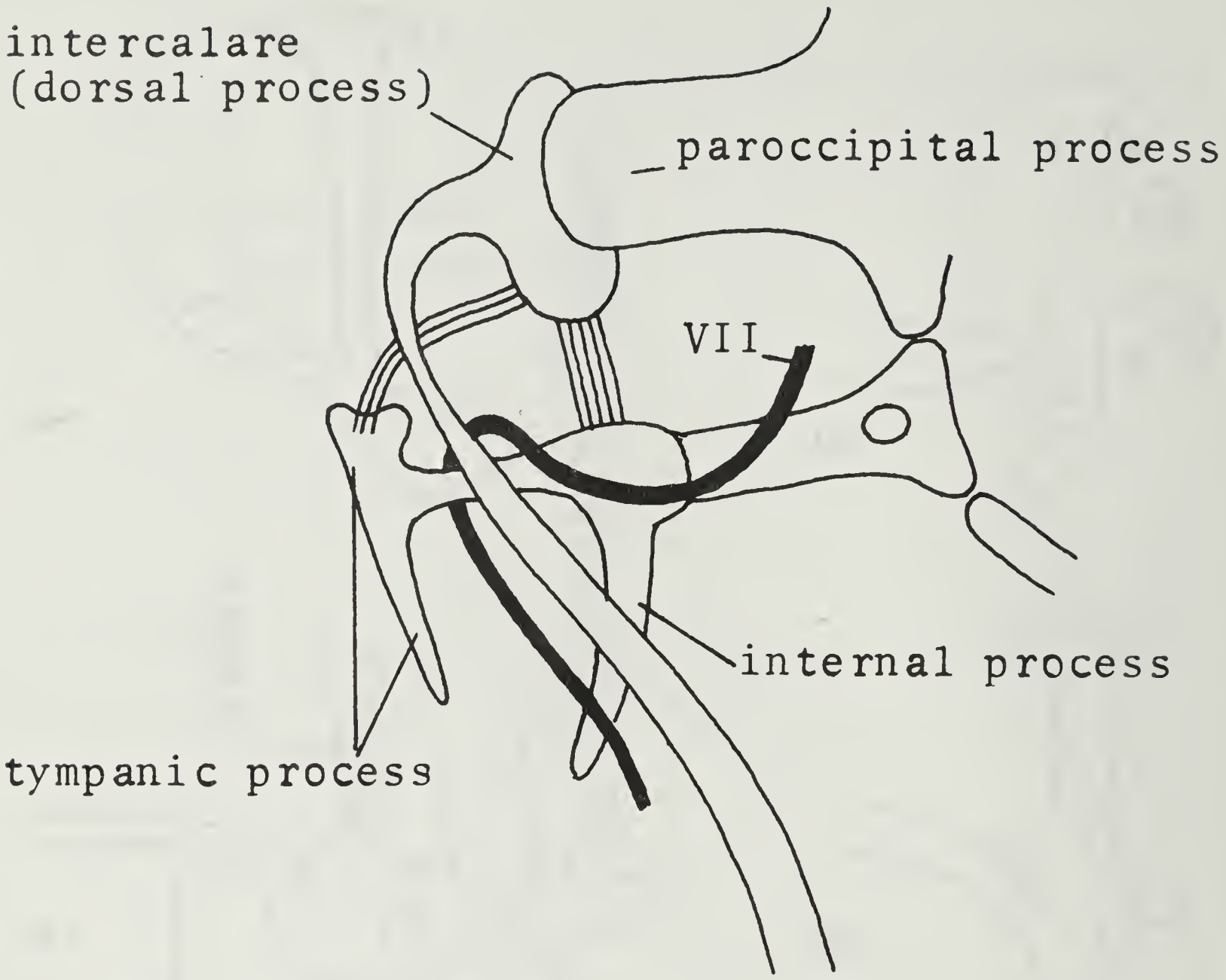


Figure 6. Adult lacertilian columella as seen from the rear (after Versluysm, 1936).

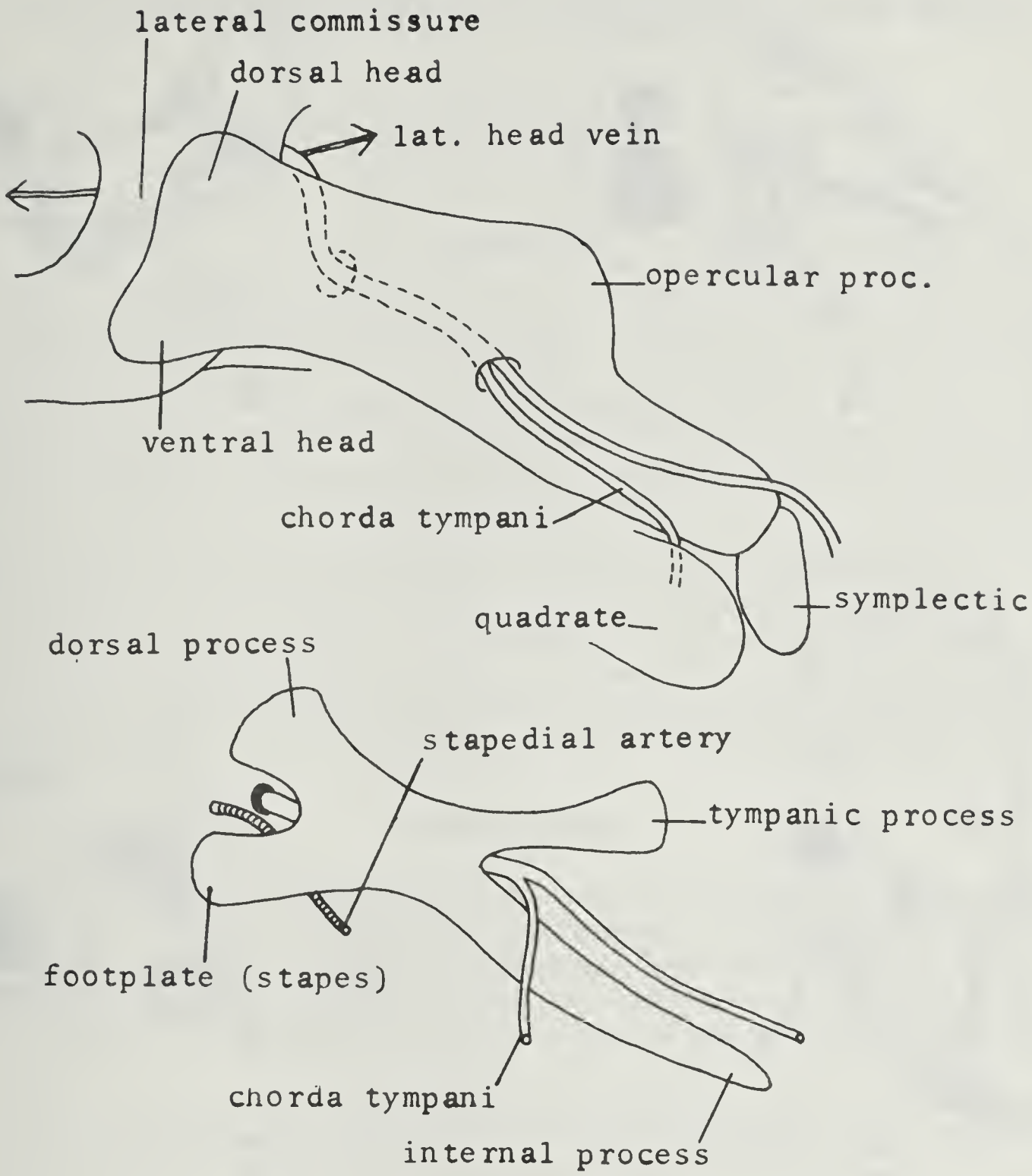
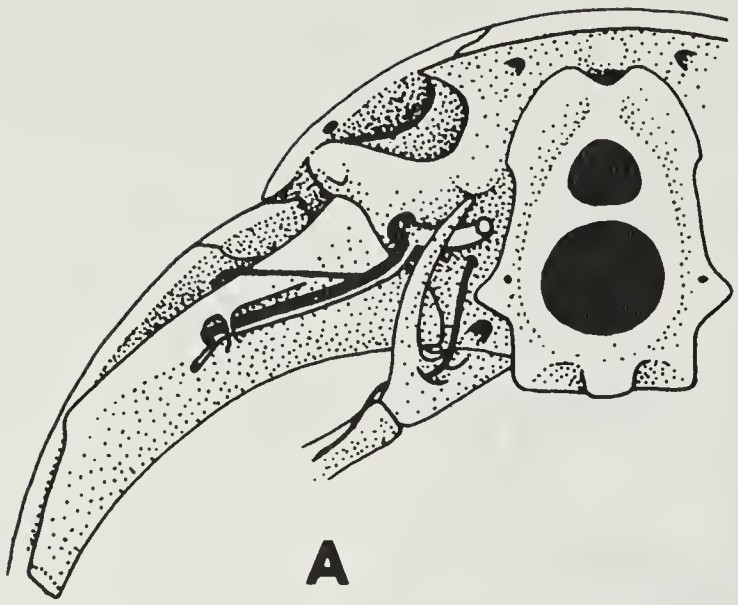
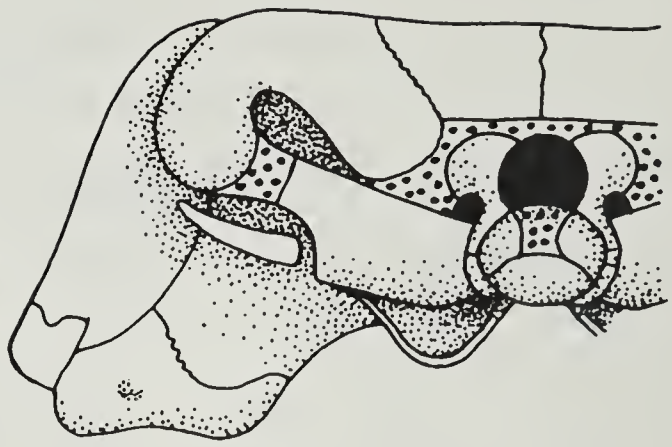


Figure 7. Transformation of hyomandibula of crossopterygian into collumellar apparatus (after Hotton, 1960).



A



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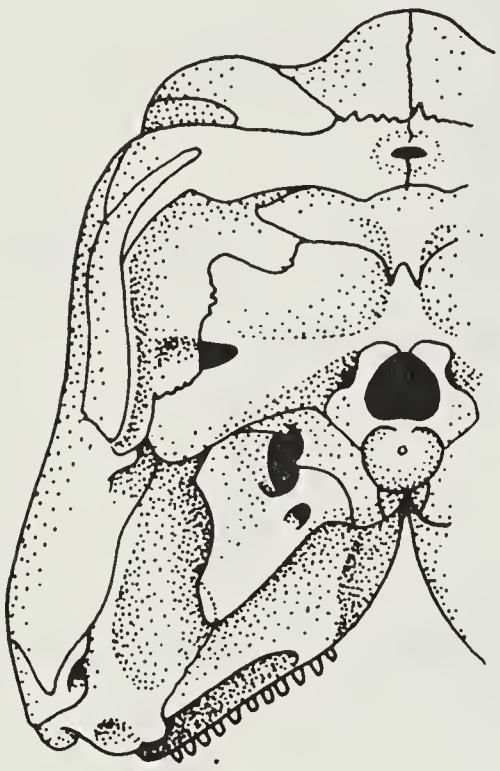

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Figure 8. The ''stapes'' of some fossil forms. a. *Eusthenopteron* (after Jarvik, 1954), b. *Seymouria,* c.*Dimetrodon,* d. *Captorhinus* (b,c,d after Romer, 1956). *See* Romer, 1956, for identification of bones.

SPECIES, ABUNDANCES, AND HABITAT PREFERENCES OF DIURNAL RAPTORS WINTERING ON CRAB ORCHARD NATIONAL WILDLIFE REFUGE

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ABSTRACT

The species, abundances, and habitat preferences of diurnal raptors on Crab Orchard National Wildlife Refuge (CONWR) were investigated during the winter of 1978-79 using the car strip census method. Ten species of raptors were observed. Red-tailed hawks (*Buteo jamaicensis)* and American kestrels (*Falco sparverius)* were most frequent and accounted for 65.2 and 14.3% of the observations, respectively. Preference values were calculated for each habitat and species based on the amount of habitat available and the number of observations in that habitat. Open terrestrial habitats, with exception of corn fields, were generally preferred by red-tailed, red-shouldered (*B. lineatus)*, and rough-legged (*B. lagopus)* hawks. American kestrels showed strong preference for milo fields. Observations of sharp-shinned hawks (*Accipiter striatus*), Cooper's hawks (*A. cooperii)*, and golden eagles (*Aquila chrysaetos)* were too few to calculate preference values. A single goshawk (*A. gentilis)* was observed, but this species is not a regular winter resident on CONWR. Two observations on ospreys (*Pandion haliaetus)*, probably of the same bird, were made; it is doubtful that this species remained on the Refuge throughout the winter due to the absence of open water. Bald eagles (*Haliaeetus leucocephalus)* preferred permanently flooded timber and Crab Orchard Lake.

INTRODUCTION

Declines in many species of raptorial birds have concerned conservationists for several years. White (1974) distinguished 5 major reasons for these declines: 1) reduction of habitat by humans; 2) reduction in the amount of food; 3) chemical pollutants, primarily chlorinated hydrocarbons; 4) direct mortality by shooting and electrocution; and, 5) exploitation for personal or economic gain. Of these factors, habitat destruction seems to have had the greatest detrimental effect (White, 1974).

The objectives of this study were to: 1) determine the species composition and abundances of diurnal raptors (Falconiformes) wintering on Crab Orchard National Wildlife Refuge (CONWR); and 2) determine the habitats preferred by wintering diurnal raptors on CONWR.

STUDY AREA

CONWR comprises approximately 17,390 ha located primarily in Williamson County, southern Illinois. The Refuge was created by Congress in 1947 for the purposes of providing wintering areas for migratory waterfowl, public recreation, agriculture, and industrial sites.

The study area was an 8,700 ha inviolate (i.e., closed to the public) portion of the Refuge consisting of a variety of well-interspersed habitats (Table 1). Croplands are farmed on a 4-year rotation plan with 2 years in corn or milo followed by 2 years in clover. Farmers leave 25% of the crop standing as food for wintering Canada geese (*Branta canadensis*). Pastures were grazed from 1 May through 31 September 1978. Industry occupies approximately 300 ha on the inviolate area.

METHODS

The car strip census (Craighead and Craighead, 1956) was used which consisted of counting raptors observed within an estimated 0.4 km strip on each side of the road while driving at a speed of 8 to 24 km/hour. The variability in speed was determined by visibility through and the density of a particular habitat.

Because raptors are frequently associated with open habitats and stay within restricted areas, a car census is usually practical and reliable. Two sources of error may occur, however. First, variation among counts may result from using observers with differing degrees of experience. To reduce this possibility, the same observers (Zoology graduate students) were used as often as possible. Second, some raptors may not have been seen in forested areas or on low perches. Repeated censuses reduced these problems as most diurnal raptors fly or perch high in trees except while capturing prey (Craighead and Craighead, 1956, pp. 47, 51). Following Craighead and Craighead (1956, p. 58), I applied a correction factor of 1.5 to the mean number of kestrels (*Falco sparverius*) observed/census to account for the small size and reduced visibility of these birds. I felt that this correction factor made the data more accurate although no attempt was made to determine if the factor was of the proper magnitude.

A 37.3 km snow-plowed census route representing the various habitats on the inviolate portion of the Refuge was chosen. Another correction factor was required to account for differences in amounts of the various habitats on the census route compared to those on the inviolate area as a whole. The areas of the habitats along the census route were determined and divided into the areas of the corresponding habitats for the entire inviolate area. The number of observations of raptors in a given habitat was then multiplied by the appropriate correction factor.

The 9 forest divisions in Table 1 were combined into a single category (forest) as it was difficult to identify the various forest types while censusing. Most of the forested areas did not contain large, mature trees. A mature hardwood forest in the eastern part of the inviolate area was not accessible by car and, thus, the number of woodland hawks (accipiters) was probably underestimated.

Oldfields were defined as those habitats consisting primarily of perennial herbs [e.g., goldenrods (*Solidago* spp.), broomsedge *(Andropogon virginicus)],* woody vines and shrubs [e.g., multiflora rose (*Rosa multiflora*), blackberry and raspberry (*Rubus* spp.)], and, in some cases, small trees [e.g., persimmon (*Diospyros virginianus*), sassafras (*Sassafras albidum*)].

Censuses were driven 20 times 12 January through 17 February 1979. Only fair weather days (i.e., clear to partly cloudy skies, wind velocity less than 24 km/hour, no precipitation, and temperature greater than -18°C) were utilized to maximize the number of sightings of raptors. Censuses began between 1000 and 1200 to allow a 3-hour period of sufficient light for accurate identification.

At least 1 observer other than the driver was present so that both sides of the road could be observed. The species, sex, and age (adult or juvenile) of raptors observed were recorded when possible using binoculars and spotting scopes. Short stops, generally less than 1 minute in duration, were made when needed for accurate identification. Individual characteristics, location, habitat where first sighted (or directly below flying birds), and activity (flying, perched, feeding, vocalizing) were noted.

Habitat preference values (HPV) were calculated in a similar manner as food preference ratings (see Petrides, 1975, The equation:

$$HPV = \frac{\%\text{ of observations of a particular species in a given habitat}}{\%\text{ of the given habitat available}}$$

leads to a preference value centering on 1.00. Habitats with preference values greater than 1.00 are preferred while those with values below 1.00 are avoided. A value of 1.00 indicates that a habitat is utilized in the same proportion as it is available. These values were calculated for species with at least 10 observations.

Table 1. Habitat divisions of the inviolate portion of Crab Orchard National Wildlife Refuge (U.S. Dept. of the Interior, unpublished data, 1966).

Habitat	*Area* (ha)	% of Total
Oak-hickory forest - *Quercus* spp., *Carya* spp.	245	2.9
Lowland hardwood	1310	15.6
Upland hardwood	298	3.6
Pin oak *Q. palustris*	204	2.4
Pine *Pinus echinata, P. taeda*	248	3.0
Black locust *Robinia pseudoacacia*	55	0.7
Post oak-Black oak *Q. stellata, Q. velutina*	89	1.1
Cottonwood *Populus deltoides*	25	0.3
White Oak *Q. alba*	11	0.1
Permanently flooded timber	162	1.9
Brush	366	4.4
Sassafras-Persimmon *Sassafras albidum, Diospyros virginiana*	826	9.9
Corn[a]	890	10.6
Milo[a]	405	4.8
Clover[a]	971	11.6
Grazed[a]	1044	12.5
Water	1233	14.7

[a]1978 figures.

RESULTS AND DISCUSSION

Ten species of raptors were identified during the study (Table 2). Red-tailed hawks (*Buteo jamaicensis*) and American kestrels were most frequently seen, and accounted for 65.2 and 14.3% of the observations, respectively. These 2 species were the most frequently reported hawks on Illinois Christmas censuses from 1974 through 1978 (Illinois Audubon Bulletin, Spring issues 1975-1979) (summarized for the period 1903-1955 by Graber and Golden, 1960).

Buteos

Most open terrestrial habitats were preferred by the 3 species of buteos (Tables 3, 4). Insufficient ground cover to support small rodents on which these birds feed (Bent, 1937; Craighead and Craighead, 1956, p. 44) may have reduced use of corn fields.

Habitat partitioning became apparent when comparing maximum preference values for the buteos. Red-tailed hawks strongly preferred milo fields, whereas red-shouldered hawks (*Buteo*

Table 2. Diurnal raptors observed on the inviolate portion of Crab Orchard National Wildlife Refuge, by age class, 12 January through 17 February 1979.

	Number of observations			
Raptor	Immature	Adult	Unknown	Total
Red-tail hawk	143	263	42	448
Red-shouldered hawk	4	26	0	30
Rough-legged hawk[a]	—	—	18	18
Unknown buteo	—	—	32	32
Sharp-shinned hawk	0	4	0	4
Cooper's hawk	0	1	0	1
Goshawk	1	0	0	1
Unknown accipiter	—	—	2	2
American kestrel[a,b]	—	—	98	98
Osprey[a]	—	—	2	2
Bald eagle	20	14	—	34
Golden eagle	6	2	0	8
Unknown eage	—	—	9	9

[a]Plumage characteristics do not allow separation into age classes.
[b]Includes 47 males, 28 females, and 23 birds of unknown sex.

Table 3. Numbers of observations of diurnal raptors in different habitats on the inviolate portion of Crab Orchard National Wildlife Refuge, 12 January through 17 February 1979.

	Habitat[a]								
Raptor	OF	MI	CO	CL	GR	FO	FT	LA	Total
Red-tailed hawk	129	118	43	75	62	14	14	3	448
Red-shouldered hawk	19	3	1	5	0	0	0	2	30
Rough-legged hawk	1	2	0	6	7	1	0	1	18
Unknown buteo	9	5	2	7	1	5	2	1	32
Sharp-shinned hawk	2	0	0	0	0	1	0	1	4
Cooper's hawk	0	0	0	0	0	1	0	0	1
Goshawk	0	1	0	0	0	0	0	0	1
Unknown accipiter	0	0	0	0	0	2	0	0	2
American kestrel	35	24	8	22	9	0	0	0	98
Osprey	0	1	0	0	1	0	0	0	2
Bald eagle	2	2	3	2	1	0	8	16	34
Golden eagle	1	1	0	0	1	0	2	3	8
Unknown eagle	1	3	1	0	3	0	1	0	9

[a]Oldfield (OF), milo (MI), corn (CO), clover (CL), grazed (GR), forested (FO), permanently flooded timber (FT), and Crab Orchard Lake (LA).

lineatus) selected oldfields more than twice as often as any other habitat. Rough-legged hawks (*B. lagopus*) had nearly identical maximum preference values for clover and grazed habitats; this concurs with findings (Weller, 1964) that these hawks most often utilized pastures and meadows for hunting. This partitioning of habitats and, thus, available food supply, may help reduce interspecific competition as these 3 hawks are similar in size and anatomy and have similar food habits (Craighead and Craighead, 1956, p. 44; Schnell, 1968).

Southern Illinois is in the northernmost part of the wintering range of the red-shouldered hawk (Bent, 1937, p. 197). This, plus the reduced winter hardiness of the red-shouldered hawk compared to the red-tailed hawk (Bent, 1937, p. 180), may account for the difference in densities of these 2 hawks (Table 5). The lack of extensive open areas on CONWR is probably responsible for the low density of rough-legged hawks on the Refuge, as these hawks are primarily associated with large areas of open country (Peterson, 1947, p. 46; Bull and Farrand, 1977, p. 501).

A significant increase in the number of observations of red-tailed hawks/census occurred during the study period (Figure 1). This increase may be due to increased observers' experience and/or an influx of birds from other areas.

Accipiters

Observations of accipiters (*Accipiter* spp.) were too few to calculate preference values. Their numbers, however, were probably underestimated due to their association with woodland habitats where visibility was poor. Comparing foot census with car census data, Craighead and Craighead (1956, p. 58) found that multiplying the number of Cooper's hawks (*A. cooperii*) observed during the car census by 1.5 gave a better estimate of the population size. By applying this correction factor to the 3 species of accipiters observed in this study, 12 birds may have been in the area. This estimate was probably conservative, however, as visibility through forested areas was reduced considerably below the 0.8 km census strip width.

Although a goshawk (*A. gentilis*) was seen, this species is not normally a winter resident on CONWR for these birds generally remain in northern coniferous forests unless food shortages force them to move south (Bull and Farrand, 1977, p. 681). The most recent goshawk invasion into Illinois occurred in the winter of 1972-1973 (Burr and Current, 1974).

American kestrels

American kestrels selected milo fields more than twice as often as any other habitat. There was no significant difference in the number of observations of kestrels/census through the study period.

Census counts of kestrels were conservative, due primarily to the small size and reduced visibility of these birds. The adjusted density (Table 5) was lower than reported by Mills (1975) in central Ohio but higher than noted by Craighead and Craighead (1956) in Michigan and Enderson (1960) in east-central Illinois. This disparity may reflect differences of study areas and/or time.

Ospreys

The 2 observations of ospreys were in the same area on consecutive days and were probably of the same bird. Due to lack of open water, it is doubtful that this bird stayed on the Refuge throughout the winter, as ospreys are closely associated with aquatic habitats (Bent, 1937, p. 352; Bull and Farrand, 1977. p. 469).

Eagles

Observations of golden eagles (*Aquila chrysaetos*) were too few to calculate preference values. Although these birds are regular winter residents on CONWR (unpublished Refuge data), they are uncommon in eastern North America (Peterson, 1947, p. 48; Bull and Farrand, 1970, p. 640).

Table 4. Habitat preference values[a] of diurnal raptors wintering on the inviolate portion of Crab Orchard National Wildlife Refuge, 12 January through 17 February 1979.

	Habitat[b]							
Raptor	OF	MI	CO	CL	G R	FO	FT	L A
Red-tailed hawk	1.55	4.04	1.12	1.07	0.79	0.16	0.54	0.06
Red-shouldered hawk	3.40	1.54	0.39	1.07	0.00	0.00	0.00	0.58
Rough-legged hawk	0.30	1.70	0.00	2.14	2.24	0.26	0.00	0.47
American kestrel	1.92	3.76	0.95	1.44	0.53	0.00	0.00	0.00
Bald eagle	0.32	0.90	1.02	0.39	0.17	0.00	14.21	4.02

[a]See text for explanation.
[b]Oldfield (OF), milo (MI), corn (CO), clover (CL), grazed (GR), forested (FO), permanently flooded timber (FT), and Crab Orchard Lake (LA).

Table 5. Densities of diurnal raptors[a] wintering on the inviolate portion of Crab Orchard National Wildlife Refuge, 12 January through 17 February 1979.

Raptor	Density[b] (1 bird/—km^2)
Red-tailed hawk	1.3
Red-shouldered hawk	19.9
Rough-legged hawk	33.2
American kestrel	4.1 (2.7)[c]

[a]Eagles are excluded for reasons discussed in the text.
[b]Calculated only if > 10 observations were made.
[c]Adjusted to account for reduced visibility of these birds. See text for explanation.

Bald eagles (*Haliaeetus leucocephalus*) preferred permanently flooded timber and Crab Orchard Lake. Their numbers, however, were highly variable among locations. These birds appeared to move readily from 1 area to another, depending on availability of food.

The car census technique is probably not an accurate method of censusing eagles on CONWR for these birds move a great deal within the Refuge and probably between CONWR, Union County Conservation Area (38 km south of CONWR), Horseshoe Lake Conservation Area (72 km south of CONWR), and Rend Lake (40 km north of CONWR).

ACKNOWLEDGEMENTS

I wish to thank Dr. D.W. Sparling, Dr. W.D. Klimstra, and Dr. B.M. Burr for their assistance throughout this study. Gratitude is extended to Wayne Adams, manager of Crab Orchard National Wildlife Refuge, for allowing access to the study area. Ross Adams, Refuge biologist, forwarded helpful suggestions and made habitat data available. This study could not have taken place without the help of the observers who accompanied me on the censuses. To these people I extend my sincere thanks.

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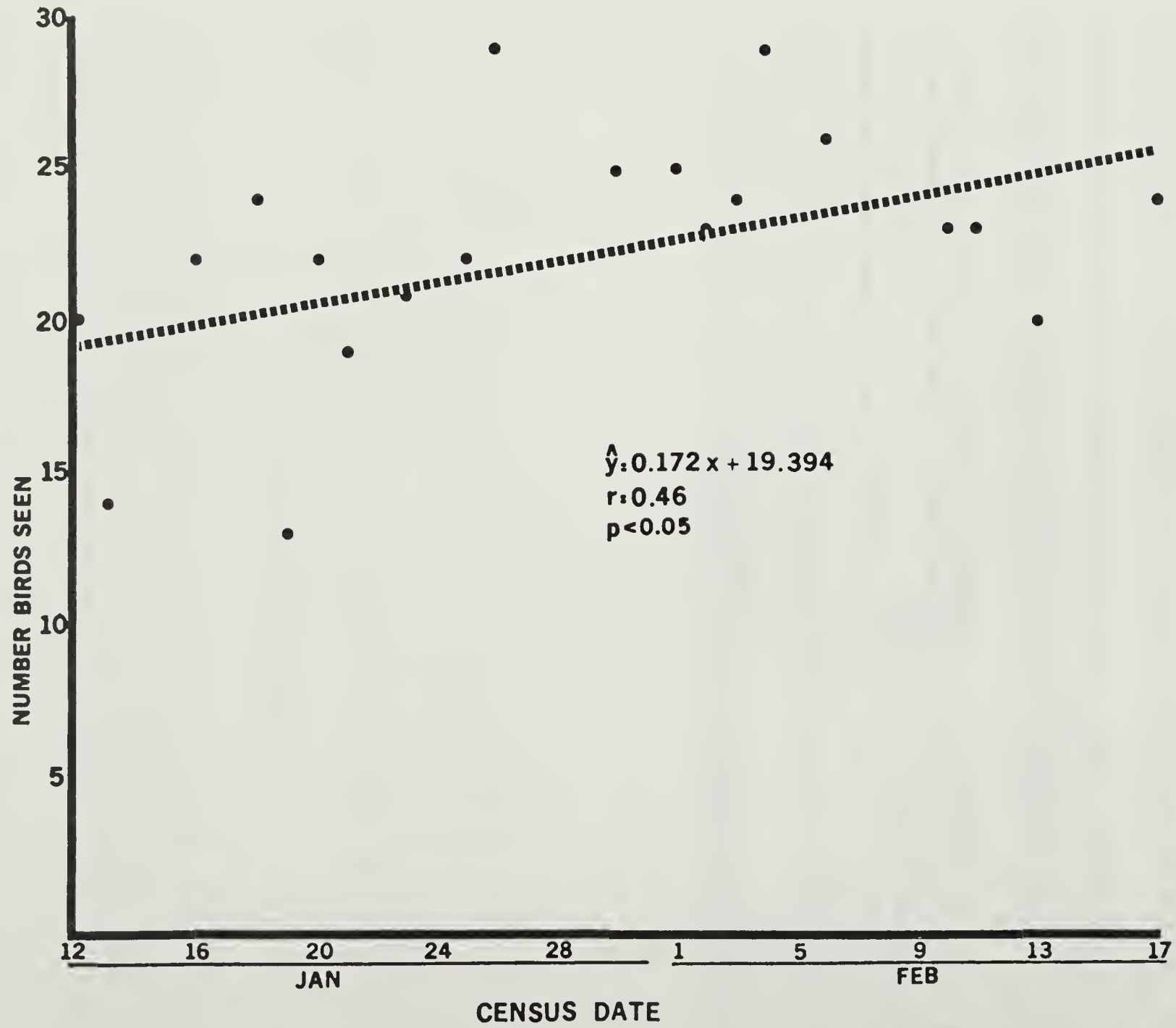

Figure 1. Change in numbers of observations of red-tailed hawks in the inviolate portion of Crab Orchard National Wildlife Refuge, 12 January through 17 February 1979.

Permeation Tubes for the Generation of Sulfur Dioxide and Ammonia at the P.P.M. Level

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ABSTRACT

Teflon (tetrafluoroethylene polymer) permeation tubes of liquid sulfur dioxide and liquid ammonia have been constructed which were used to generate two separate streams of sulfur dioxide and ammonia at the concentration levels of 224 and 172 p.p.m., respectively. These two separate streams of gases in moist air (flow rate of 100 ml/min/air stream) were mixed in a vertical, cylindrical mixing chamber (50 cm x 2.4 cm). Residence time in the all glass apparatus was less than 10 min. as calculated from dead volume space and flow rate. Sulfur dioxide concentrations were established by a colorimetric method, and the ammonia concentrations were determined by collection in a standardized hydrochloric acid solution. Permeation tubes are an excellent way to produce low concentrations of gases at a constant flow rate, and the illustrated experimental apparatus represents a convenient way to study the interaction of gases at low concentrations where flow rates can be easily controlled.

Sulfur dioxide and ammonia permeation tubes were constructed, and illustrated a very convenient way to liberate small concentrations of gas for prolonged periods of time. Sulfur dioxide and ammonia were chosen to determine the efficiency of ammonia's ability to remove sulfur dioxide from a moist air stream at fairly low concentrations. To make an experiment relevant to today's problems, we chose this mixture because of sulfur dioxide's potential hazard in the enviornment.

Sulfur dioxide is classified as a primary pollutant in our atmosphere, and is considered hazardous to vegetation when the ground levels exceed 0.3-0.5 p.p.m.[1] The National Air Quality standards recommended by the EPA (July 1, 1975)[2] suggested an annual arithmetic mean of 0.03 p.p.m. and a 24-hr. mean of 0.14 p.p.m. which is not to be exceeded but once a year.

Coal burning facilities must also be cognizant of the sulfur dioxide problem because they have to remove sulfur dioxide at the 75% efficiency level when burning high sulfur coal (approximately 3%) to meet the New Source Performance Standards. In fact, most State Implementation Plans require an efficiency removal level of 85%.[3]

EXPERIMENTAL

Reaction Chamber. The experimental apparatus is shown in Figure I. This is an all glass apparatus except for the rubber tubing attached from the air jets to the impingers containing the water and rubber tubing attached from the three-way valves to the flow meter.

Air flow is generated from laboratory air jets which first enters impingers A and G, both of which contain water. The reason for this is to give a saturated air flow which is similar to what is encountered in high humidity stack gases. The saturated air flow is checked by attaching a soap film flow meter to one end of a three way valve at B & H. The flow rate can be easily changed by adjusting the air jets. The flow rate used for the experimental runs was 100 ml/min of water saturated air through impinger A and G. From impinger A, air flows into impinger C which contains the permeating tube pressurized with liquid sulfur dioxide which diffuses out at a constant rate.

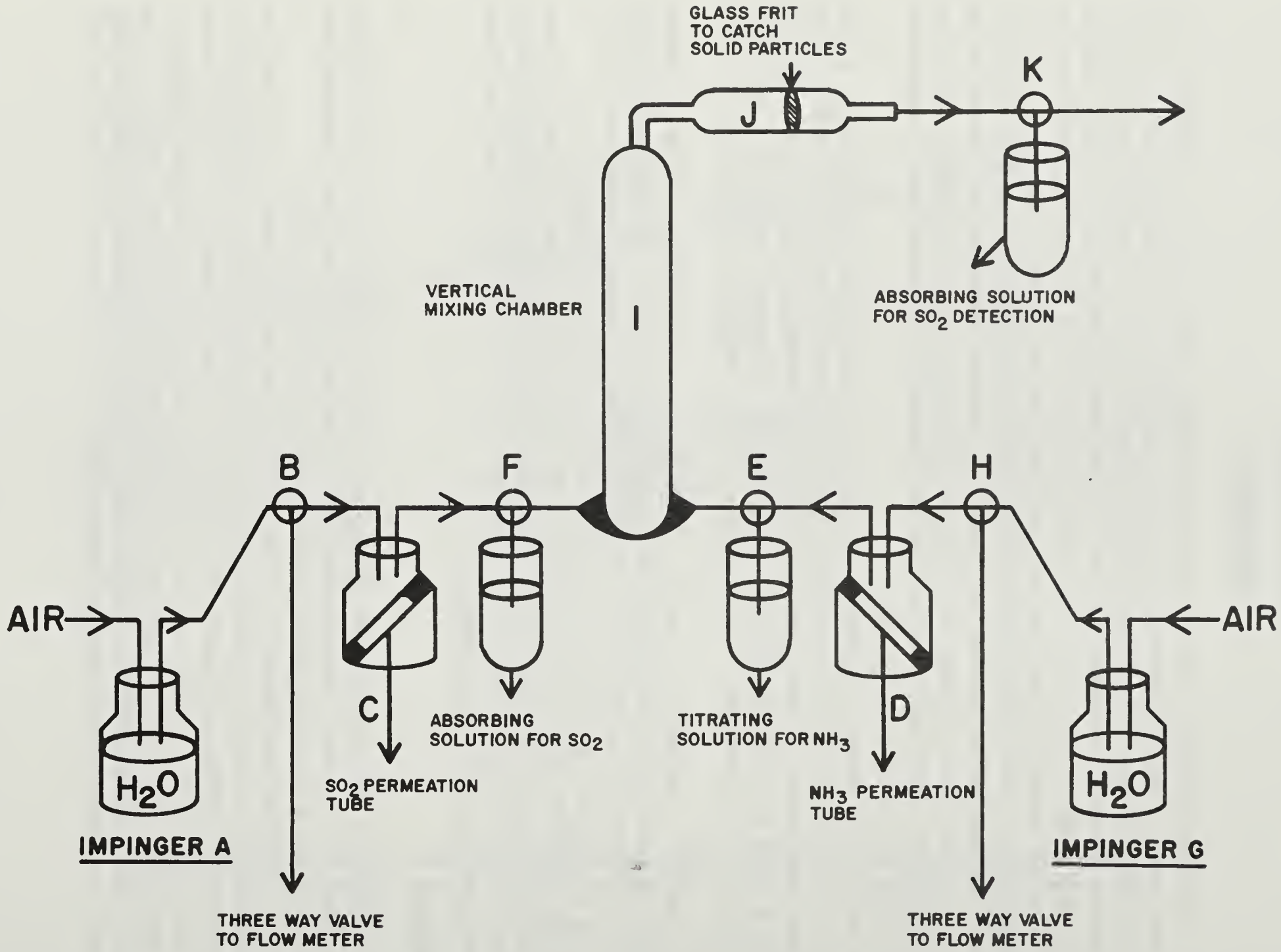

FIGURE I. EXPERIMENTAL APPARATUS

From impinger C, the mixture of sulfur dioxide and saturated air is passed (or can be) into an absorbing solution for sulfur dioxide (F) which is used to calculate the concentration of sulfur dioxide before it is sent into the vertical mixing chamber I.

From impinger G, the saturated air, which also flows at 100 ml/min, is passed into impinger D. Impinger D contains the permeation tube containing liquid ammonia which diffuses out and mixes with the moist air. From impinger D, the ammonia and saturated air is passed into a standardized hydrochloric acid solution (0.1000 N HCL), which is back titrated with 0.1000 N sodium hydroxide to determine the concentration level of the ammonia generated at D.

After concentrations of sulfur dioxide and ammonia are determined, the two gasses are passed into the vertical mixing chamber I and allowed to react. Residence time in this mixing chamber was 9.04 minutes (1808cc. volume). A medium glass frit, chamber (J), follows the mixing chamber to catch the solid particles of ammonium hydrogen sulfite. The unreacted ammonia and sulfur dioxide penetrate the frit and enter another absorbing solution K which is used for the calculation of the unreacted sulfur dioxide.

Permeation Tubes. The method of generating p.p.m. concentrations of sulfur dioxide and ammonia is through the construction of permeation tubes. Permeation tubes can be made from any inert plastic or porous material if it has the appropriate physical properties. Both FEP (fluorinated ethylene-propylene copolymer) and TFE (tetrafluoro-ethylene polymer) Teflon have been used.[4] The tube type that was chosen for this experiment was the TFE Teflon tubing (¼ inch outside diameter ranging in length from about 5 to 10 cm.). Sealing of the Teflon tube was done by inserting a Teflon plug into the end of the tube and placing this end into a glass heater (a tapered glass apparatus open at both ends with an initial diameter just large enough so at least ⅓ to ¼ of an inch of the tube can be inserted). The glass apparatus was wrapped evenly with nichrome wire attached to a variac (auto-transformer) for temperature regulation. The Teflon tube was left inserted in the heater until the heating coils became a dull red. Enough heat was transferred from the coils to the Teflon tube to cause the Teflon to begin to melt (260°C). The end was checked for leaks, once it has cooled, putting 30 to 35 p.s.i. of nitrogen on the opened end of the tube and simply submerging the sealed end into water for the leak check. If no leaks were observed, this always indicated a good end of a perfect seal. Next the sealed end was submerged into a Dewar flask containing a slurry of dry ice and acetone. The gas (ammonia or sulfur dioxide) was fed into the tube which condensed to a liquid. Once the liquid level reached three-fourths the total volume of the tube, a Teflon plug was inserted into the open end. This end was inserted into the glass heating apparatus (keeping the liquid portion of the tube submerged in the acetone slurry) for end sealing.

Once a good seal was made, the whole tube was removed and allowed to equilibrate to room temperature, at which times both ends were rechecked for leaks by submerging the ends into carbon tetrachloride. (*Tubes should be well protected when sealed and allowed to come to room temperature.*) If leaks were observed (usually it was the newly sealed end), one places the tube back into the Dewar flask, cuts off the poorly sealed end, inserts a new Teflon plug, and completes the sealing procedure again.

All tubes, especially after the contents are under pressure, should be handled with caution. Since they have been chilled with dry ice during filling, room for liquid expansion should be provided to prevent breakage of the seals. Tubes should be protected from excessive heat, and they should not be scratched, bent or mechanically abused. Properly sealed permeation tubes last approximately three months while generating concentration levels in the p.p.m. range.

Ammonia and Sulfur Dioxide Determinations. Determination of ammonia concentrations employed a flow rate of 100 ml/min of moist air passing through impinger D which contained the permeation tube of ammonia. The exit gases were bubbled into a solution containing 2.0 ml of 0.1000 N HCl for one hour. The titration of the excess HCl was done with 0.1000 N NaOH and indicated 172 p.p.m. of NH_3.

The determination of sulfur dioxide was done by an analytical method of West and Gaeke.[5] Standard sulfite solutions were made to construct a standard calibration curve of absorbance vs. concentration (ug of sodium hydrogen sulfite) from which the concentration of sulfur dioxide was

determined. The initial concentration of sulfur dioxide was 224 p.p.m. from the exit of impinger C. These sulfur dioxide experiments were five minute runs.

Sulfur dioxide reacts with sodium tetrachloromercurate (II) and forms sodium disulfiteomercurate (II). This salt, in the presence of rosaniline hydrochloride and formaldehyde, forms a red-violet colored solution. The absorbance of this solution gives the sulfur dioxide concentration when compared to a standard calibration curve.

Concentration of sulfur dioxide were measured before and after mixing with ammonia, and the average percent removal in the four trials was 95.90% ± 0.285% average deviation.

Gas flow rates from permeation tubes are a function of temperature, however, in these experiments no control of temperature was maintained. All experiments were done at ambient temperatures.

Absorbancies of each solution were determined by comparing them to distilled water at 560 nm. These data for the calibration curve of absorbancies vs. concentration are shown in Figure II.

Experiments with the ammonia mixing with the sulfur dioxide had two streams of these gases mixing in the vertical chamber I. These gas streams were mixed for a duration of 10 minutes, e.g., 100 ml/minute of moist air with 172 p.p.m. of ammonia mixing with 100 ml/minute of moist air containing 224 p.p.m. of sulfur dioxide. After exiting to the atmosphere at K for 10 minutes, the air stream was bubbled through the absorbing solution at K for 5 minutes.

RESULTS

The chemical reaction between sulfur dioxide and ammonia is as follows: $NH_3 + SO_2 + H_2O \longrightarrow NH_4HSO_3$. Undoubtedly, some ammonium sulfite is formed, $2NH_3 + H_2O + SO_2 \longrightarrow (NH_4)_2SO_3$ but no attempt was made to ascertain either of these solid chemicals. Solid particles were formed in the mixing chamber as evidenced by white particles forming on the sides of the chamber. In addition, solid particles would collect in the glass frit (J) and would restrict its flow-through drastically after a 25-minute run. Reversing the flow of air through the frit would restore it for another experimental run. To prevent clogging at the glass frit, glass wool packing was placed in front of the frit without success. Possibly a vertically positioned frit could prevent part of the clogging problem.

Since the gas stream for ammonia was 172 p.p.m., this corresponds to a microequivalents of 10.1 per gram of moist air. For sulfur dioxide, the 224 p.p.m. corresponds to 3.50 microequivalents. Consequently, in the mixing chamber there is a 6.6 microequivalents excess of ammonia over sulfur dioxide.

To ascertain how much sulfur dioxide was lost in the apparatus by adsorption on the walls of the glass apparatus, two determinations were run with the ammonia stream turned off at E (Figure 1). The sulfur dioxide concentration was checked at point F and at point K. Duration of these sample runs were 5 minutes, and the sulfur dioxide decrease was 11.8 ± 0.2 p.p.m.

Data for four trial runs are shown in Table 1. These data reveal that the average removal of sulfur dioxide, based on the correction for p.p.m. lost on the glass surface, was 95.9 ± 0.285%.

SUMMARY

This laboratory experiment was performed to determine the effect of ammonia on the removal of sulfur dioxide at the p.p.m. level. The experimental apparatus is an all glass closed system, and the concentrations of sulfur dioxide and ammonia were generated through teflon permention tubes of ¼ inch in diameter and from 10 to 20 cm in length.

Concentrations of ammonia were determined by back titrating with 0.1 N sodium hydroxide a solution containing 2 ml of 0.1 N hydrochloric acid which the ammonia had bubbled in for one hour. The concentrations of sulfur dioxide were determined spectrophotometrically.

The products of the reaction of sulfur dioxide and ammonia were ammonium hydrogen sulfite and ammonia sulfite. Mixing of these two gases in the vertical mixing chamber clogged the glass frit causing flow rate distortion if mixed for 25 minutes or longer.

Table 1. Experimental Results of Sulfur Dioxide Removal by Ammonia at the p.p.m. Level

Trial	Abs. before mixing	ppm	Abs. after mixing	ppm	percent removal	ppm adjusted for amount lost on glass surface	adjusted percent removal
1	0.3857	371.63	0.0642	2.53	99.31	357.09	95.69
2	0.3784	364.87	0.0642	2.53	99.30	351.34	95.60
3	0.4212	388.51	0.0606	2.03	99.47	347.98	95.99
4	0.4569	449.32	0.0678	2.79	99.38	435.79	96.36

Average percent removal. . . . . 95.90 ± 0.285

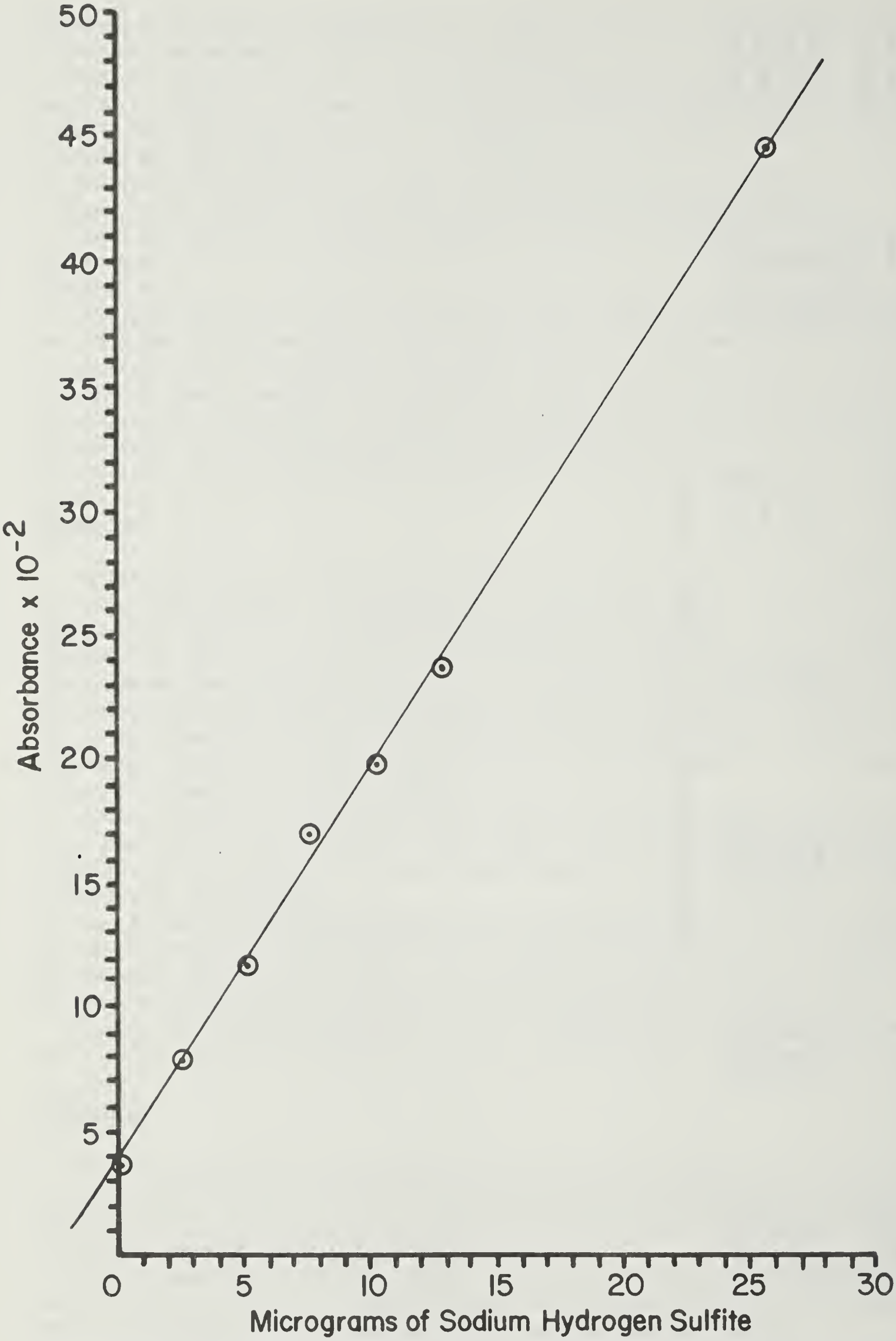

FIGURE 2. CALIBRATION CURVE - ABSORBANCE VS. CONCENTRATION

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LIMNODRILUS RUBRIPENIS LODEN AND *PSAMMORYCTIDES CALIFORNIANUS* BRINKHURST, TWO AQUATIC WORMS (ANNELIDA: OLIGOCHAETA: TUBIFICIDAE) NEW TO ILLINOIS

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ABSTRACT

Limnodrilus rubripenis Loden was taken from 1 location in Union County, Illinois, during January 1976, from 2 locations in Johnson County, Illinois, during February 1976, and from one location in Johnson County during April 1976. *Psammoryctides californianus* Brinkhurst was taken from 2 locations in Union County, Illinois, during February 1976. These records are the first for each species in Illinois.

INTRODUCTION

The waters of Illinois offer a variety of habitats, including springs, seeps, swamps, marshes, ponds, lakes, reservoirs, brooks, streams, and large river systems. Although comprehensive faunal studies of aquatic invertebrates and vertebrates in Illinois have been conducted and updated, the aquatic Annelida has remained a neglected group in this state, with the exception of faunal studies on Lake Michigan species. Much of the existing information is contained in environmental assessments and other reports with limited distribution. Recent exceptions include Howmiller (1974) and Singer (1978), although the distributional data in these papers is quite restricted. I present this short note as the first in a series of articles which will thoroughly review past research as well as our current knowledge of aquatic Oligochaeta in Illinois.

METHODS

Specimens were collected with a D-ring net from shallow (6 to 60 cm) habitats, each with substrate composition of approximately 75% silt-mud, 15% sand, and 10% detritus. Specimens were fixed in Kahle's fluid, returned to the laboratory and sorted into 70% ethanol, cleared in Amman's lactophenol, and mounted in Hydramount.[R] Amman's lactophenol macerates and destroys internal tissues, limiting further diagnostic work. A preferred method would include dehydrating the specimens through an alcohol series, clearing in either xylene or methyl salicylate, and mounting in Canada balsam or some other resinous medium. Voucher specimens of these species have been deposited in the collections of the Illinois Natural History Survey, Urbana.

DISCUSSION

Limnodrilus rubripenis was described by Loden (1977) from Hog Branch, 4.8 km ESE Livingston, Livingston Parish, Louisiana. This species is reported here for the first time to occur outside the type locality. Specimens of *L. rubripenis* were collected from 3 localities in Illinois. Two specimens were collected from Lick Creek in Union County, 2.7 km NW Lick Creek (town) on 29 January 1976. Lick Creek at this location is in a forested area with light vegetation and moderate root outcroppings along the banks. This stream has a mean width of 2 m, mean depth of 20 cm, and a moderate flow. The substrate is principally of a sand-gravel-cobble mixture, although frequent pools contain silt, mud, and detritus. Two more specimens were taken from Cave Creek in Johnson County, 6.0 km NE Belknap, on 27 February 1976. Cave Creek at this location is in a forested and agricultural area, with heavy vegetation along the banks. This stream has a mean

width of 3 m, a mean depth of 40 cm, and a very low flow. The substrate is primarily of a clay-sand-gravel mixture, although numerous pools of silt and detritus can be found. A third specimen from this location was taken on 29 April 1976. Two additional specimens were collected from Lick Creek in Johnson County, 7.2 km SSW Goreville, on 28 February 1976. This location on Lick Creek, 16 km downstream from the other Lick Creek site described above, is a dredged channel in an agricultural area, with moderate vegetation along the banks. The channel here has a mean width of 5 m, a mean depth of 75 cm, and a moderate flow. The substrate is primarily clay, with numerous pools of silt-mud and detritus.

Psammoryctides californianus was described by Brinkhurst (1965) based upon a single specimen from Coyote Creek, Santa Clara County, California. Brinkhurst (1976) suggested that this species might occur in the western Canadian provinces and then documented (1978, 1979) its presence in Airport Creek on the Saanich Peninsula near Sidney, British Columbia. Douglas R. Spencer (pers. comm.) has since collected this species from Cayuga Lake, New York, and the Black River in St. Claire County, Michigan. He also noted the presence of this species in the St. Marys River, between Lake Superior and the lower Great Lakes, but provided no further information (Spencer 1979). Loden (1978) revised the genus *Psammoryctides,* erecting the subgenera *Psammoryctides* new status and *Spencerius* subgen. nov. for separation of North American and European forms. *P. californianus* now becomes *P. (Spencerius) californianus* Brinkhurst.

Specimens of *Psammoryctides californianus* were collected from two localities in Illinois. One specimen was taken from the Cache River in Union County, 9.7 km E Anna, on 29 January 1976. The Cache River at this location is a dredged channel as it passes under the Interstate 57 bridges. The reaches on either side of the 0.2-km dredged area pass through broken woods and small agricultural plots. The banks are grass- and shrub-covered. The channelized river at this location has a mean width of 5 m, a mean depth of 90 cm, and a low flow. The substrate is primarily deep mud-silt with some detritus. Two other specimens were taken from Lick Creek in Union County, 2.7 km NW Lick Creek (town), on 29 January 1976. This station has been described above.

Over 4,000 aquatic oligochaetes, representing 6 families, 17 genera and 29 species, were identified from the upper Cache River system in southern Illinois. The distributional information presented here for *Limnodrilus rubripenis* and *Psammoryctides californianus* suggests that these two species are rare when present. However, future investigations will probably extend their range.

ACKNOWLEDGEMENTS

I wish to thank Michael S. Loden for confirming my identification of *L. rubripenis,* and Douglas R. Spencer for bringing to my attention the occurrence of *P. californianus* in material sent to him from this area. I would also like to thank both of these researchers for their encouragement of this and other research.

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A New Southern Illinois Record of *Clossiana bellona* (Lepidoptera:Nymphalidae)

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ABSTRACT

A southern extension of the known Illinois range of *Clossiana bellona* (Fabricius) is reported.

The eastern meadow fritillary, *Clossiana bellona* (Fabricius), occurs from central and southern Canada east to Quebec, south to New Jersey and the mountains in North Carolina and west to Minnesota and northern Nebraska (Klots 1951). In Illinois this butterfly occurs primarily in the northeastern part of the state (Irwin and Downey 1973) with the previous southernmost record at Edwardsville, Madison Co. (Davis 1977).

This species is probably trivoltine in Illinois (Irwin and Downey 1973), overwinters as partially grown larvae and feeds on violet (Klots 1951).

On 1 June 1980 I collected one adult male specimen near a wet meadow at Pomona, Jackson Co. This represents a southern extension of ca. 90 miles of the known Illinois distribution of this butterfly. The time of collection was 1400 and the temperature was ca. 32°C.

The specimen is deposited in the SIU Entomology Collection, Zoology Research Museum.

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DISC ELECTROPHORETIC PROFILES OF HUMAN ORGAN PROTEINS

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ABSTRACT

Protein concentrates processed from acetone-dried human organ powders were submitted to polyacrylamide disc electrophoresis and the resulting profiles correlated. With the possible exception of brain and spleen, the electrophoretic patterns were similar for kidney, lung, heart, muscle and liver (Type I). With several of the livers, the electrophoretic mobilities described another mode (Type II), the post-albumin portion exceeding that of the albumin region, the reverse of Type I. However, albumin + post-albumin components were the same for either type.

In a prior study (Gershbein and Al-Wattar, 1968), protein concentrates were derived from human term placenta, the tissue first being converted to an acetone-dried powder. Electrophoresis was carried out with various extracts and the soluble proteins characterized. Since the dried powders are stable in the cold and as the resulting soluble concentrates ('PLSR') contain prominent protein components, this approach was applied currently to various human organs removed at surgery or autopsy and the respective patterns compared.

MATERIALS AND METHODS

Organs were obtained at autopsy performed within 9 hr after death, rinsed with water to remove clots, drained, weighed and blended with redistilled acetone. After 2-7 days at 25°C, the contents were filtered and the cake washed with copious amounts of acetone and air-dried prior to storage at 4°C. Where tumor was present as in the hypernephromas, the 'normal' tissue was dissected free of lesion, a procedure which had also been employed earlier in a study of kidney lipids (Gershbein *et al.,* 1976). Organs from surgery submitted in 0.90% sodium chloride were processed in the above manner following gross pathological examination and sectioning.

The acetone-dried powders were extracted with water (10 ml/g), the filtrate freeze-dried and the resulting solid extracted exhaustively with 95% ethanol and then with water. The aqueous filtrate was dialyzed against water and the residue freeze-dried to yield the test concentrate. Solutions in 0.90% saline containing protein at 6-8 g/100 ml were submitted to polyacrylamide disc electrophoresis, each run lasting 30-40 minutes and the distance of migration into the lower gel being 3.5 cm. The gels were stained with aniline blue black and scanned in a microdensitometer. The techniques of tissue drying and extraction and electrophoresis are detailed in an earlier report (Gershbein and Al-Wattar, 1968), except that more than one gel was electrophoresed per run currently.

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[1] Deceased, February 22, 1980

Description of Cases

Autopsied cases: DB (M, 36 yr)—subacute lymphoblastic leukemia, gastric hemorrhage; LB (F, 67 yr)—diabetes, uncontrolled clinical, obesity; GD(M, 55 yr)—hypertrophic heart disease; CK(M, 18 yr)—acute lymphocytic leukemia with anemia, secondary severe; JK(M, 61 yr)—recurrent renal carcinoma and secondary carcinoma of the skeletal system; SO(M, 51yr)—generalized lymphosarcoma, splenohepatomegaly; PK (F, 52 yr)—cardiac failure; ER (M, 67 yr)—squamous cell carcinoma in the regional lymph nodes; CS(M, 67 yr)—CVA; HW (M,71 yr)—carcinoma of the prostate with metastases to the abdominal lymph nodes and liver and RW (F, 62 yr)—carcinoma of the stomach and carcinomatosis of the peritoneum, considerable fatty changes of the liver.

Operated patients: The hypernephroma cases comprised two men (56 and 60 yr) and two women (60 and 77 yr) and in the 'control' kidney group RL (F, 32 yr) presented an adenocarcinoma (clear cell) of the right kidney with acute and chronic glomerulonephritis. The lone surgical case in the splenic series was AP (M, 62 yr) with congestive splenomegaly. Muscle was removed from the right leg amputated from JJ (M, 67 yr)—obiterative arterioscleroisis with gangrene.

RESULTS

The distribution of two rapidly migrating pre-albumin peaks, PA_1 and PA_2 and the albumin, post-albumin and the *B*- and *y*-globulin regions for kidney, liver, spleen, lung, heart, brain and muscle is shown in Table 1. For the last two, a single specimen was available. With kidney, comparisons were made of the respective mean values of 4 cases with malignant nephroma against five with other pathology, including a clear cell adenocarcinoma of the kidney (RL) but the differences lacked statistical significance ($P>0.05$). In one case of nephroma, PA_1 was very faint and PA_2 showed splitting. In general, the albumin portion ranged highest among the tissue concentrates except possibly for brain and spleen. With liver, two modes could be discerned (Types I and II), the difference residing in the mobility of moieties in the albumin and post-albumin regions. With Type 1, the alumin level was almost double that of the post-albumin portion, whereas with Type II, this order was reversed. However, the sum of the 2 peaks which might have more biological significance, was essentially constant (55.2% and 56.6% for Types I and II, respectively).

DISCUSSION

The electrophoretic patterns reflect the composition of the organ proteins but the contribution of blood, especially in organs as liver, spleen and kidney must be considered. In fact, the composition for several organs parallels that of blood as such. It is almost impossible to remove all blood from such tissues in spite of copious rinsing of the diced organs with water or buffer solutions and this difficulty is inherent in most of the organ protein studies to date. Some protein denaturation also occurs with the present drying and extraction procedures and the latter must be closely followed to allow for greater uniformity among the soluble protein concentrates. The problems of contamination with blood and possible protein denaturation, notwithstanding, these PLSR concentrates allow for interesting comparisons among organs in protein composition and in various components as a result of pathology. The possible presence of blood as a contaminant is not a critical concern even among the tissues with initially high proportions of the fluid. Thus, definite differences were observed between the kidney and spleen components. Of interest, rinsed skeletal muscle, lower in blood contamination, gave rise to an electrophoretic pattern not unlike that of spleen., Although many similarities were observed among tissues with respect to overall electrophoretic regional components, wide variations might be evident by electrophoretic patterns reflecting protein fine structure, studies of which were not conducted currently.

The electrophoretic patterns with liver PLSR are remarkable. It will be noted that the Type II-profile was displayed by the 2 leukemia cases (DB and CK), one with a lymphosarcoma (SO) and

the fourth case (LB) with carcinoma of the stomach. The latter also showed fatty liver infitration. Accordingly, a study of such protein changes due to leukemia and other pathology reflecting on the liver, might be rewarding.

As compared to the above organs, placenta showed some divergence in electrophoretic behavior. The PLSR concentrates contained PA_1 and PA_2 at comparable levels, a high albumin content (52%) and *B*- and *y*-globulin regional zones, each averaging 9-11% (Gershbein and Al-Wattar, 1968). Changes in the distribution of components could be demonstrated when the mixtures were fractionated by procedures initally devised for plasma proteins by Cohn *et al.* (1946).

Table 1. Weight Percentage Distribution of Electrophoresed Components of Human Organ Proteins

Organ (no. of cases)	Pre-Albumins PA_1	Pre-Albumins PA_2	Albumin Region	Post-Albumin	β-Globulin Region	γ-Globulin Region
KIDNEY						
Hypernephroma (4)	2.75 ± 0.94	6.50 ± 2.57	40.28 ± 4.63	16.13 ±1.76	24.04 ± 3.53	14.68± 2.34
CK,PK,RL,SO,RW (5)	2.90 ± 1.11	6.72 ± 1.56	35.18 ± 1.10	17.24 ±1.02	19.00 ± 1.63	18.94 ± 1.63
Fisher t-value	0.15	0.08	1.20	0.73	1.40	1.53
LIVER						
Type I: GD,JK,ER,HW (4)	2.90 ± 1.11	4.70 ± 0.60	36.33 ± 6.07	18.88 ± 1.82	17.23 ± 3.36	20.05 ± 3.79
Type II. DB,L8,CK,SO (4)	6.30 ± 1.16	4.88±0.46	14.45 ± 2.26	42.13 ± 3.42	13.18 ± 1.06	19.10 ± 3.60
Fisher t-value	2.11	0.24	33.8**	6.01**	1.15	0.18
SPLEEN						
JK,SO,AP,ER,RW (5)	6.08 ± 2.55	9.76 ± 2.87	24.20 ± 2.43	12.10 ± 0.63	20.98 ± 3.32	27.92 ± 2.32
LUNG						
JK,SO,ER,HW,RW (5)	2.84 ± 0.98	5.22 ± 2.17	37.84 ± 2.26	13.52 ± 1.16	17.60 ± 0.85	23.02 ± 0.86
HEART						
JK,HW,RW (3)	2.37 ± 0.87	5.10 ± 1.16	42.33 ± 7.52	21.87 ± 4.00	16.43 ± 1.58	11.41 ± 3.14
8RAIN						
CS (1)	7.6	2.9	21.4	23.5	21.4	23.2
MUSCLE						
JJ (1)	5.4	3.9	31.0	14.7	21.2	23.9

For case.descriptions, see text. Each value is the mean ±SE.
** $P < 0.01$.

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Some Characteristics of Tomato Leaf Ribonucleases Stimulated by Leaf Detachment

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SUMMARY

The specific activities of ribonucleases mg^{-1} protein increased in leaflets of tomato plants when they were detached and floated on water under aseptic conditions; homogenates of these leaflets were most active at pH values of 4.8 and 5.4. These two activity peaks were separated using gel filtration, and were due to two different enzymes.

When cell-free organelle preparations were separated by differential centrifugation, the pH 5.4 enzyme was found exclusively in the mitochondrial and soluble fractions, probably bound to lipid material; it is RNA-specific.

INTRODUCTION

Nucleases are widespread in the plant kingdom, with most plants and plant parts having several types of nuclease activity which differ in their biochemical characteristics (Wilson, 1975), as well as their responses to developmental changes and environmental stresses (Dove, 1973). Matile (1975) described several types of lytic compartments which release hydrolases into the cell wall, the central vacuole, or—in the case of autophagic vacuoles—into the cytosol. The activities of these lytic compartments depend upon the physiological status of the plant tissue, which in turn depends upon tissue maturity and the degree to which the tissues are stressed.

Shumway, et al. (1970) have shown that the central vacuoles of tomato mesophyll cells of detached leaves accumulate an insoluble protein which is not present in attached leaf vacuoles. Since ribonuclease (RNase) activity increases in tomato leaves following detachment (McHale and Dove, 1968), and central vacuoles appear to be repositories for hydrolase activity (Matile, 1975), it seems reasonable to expect a membrane-bound RNase which is activated by leaf detachment. This paper describes such membrane-bound RNase activity in tomato leaflets.

MATERIAL AND METHODS

Tomato plants *(Lycopersicon esculentum,* cv. Marglobe) were grown in soil under greenhouse conditions. Leaflets from the fifth through eighth leaves, counting basipetally from the smallest leaf over 2 cm long on the main stem axis, were removed from the rachis, weighed immediately, washed twice by immersion in demineralized water and surface-sterilized (Dove and Oduola, 1980). Leaflets were either used immediately, or floated on sterile demineralized water for 24 h in a growth chamber with 15 h light at 28°C, followed by 9 h darkness at 20°C.

Enzyme Purification. Leaf material was disrupted in cold 0.05M Tris buffer using a blender, filtered through cheesecloth, and centrifuged at 16,000 g in a Sorvall RC-2B centrifuge using an SS-34 rotor. An $(NH_4)_2SO_4$ fraction was prepared from the supernatant fluid, dialyzed in buffer, and added to a 100 cm column of Sephadex G-75. Aliquots from the fractions of the column eluant were used to determine protein absorbance at 280 nm, RNase, DNase, and non-specific phosphodiesterase activities.

Organelle Isolation. Ten g of surface-sterilized leaflets were blotted in sterile paper towels, transferred to sterile petri dishes and minced in three 10 ml portions of isolation medium (0.05% Tris buffer, pH 7.5, with 0.36 M sucrose and 0.001 M $MgCL_2$, followed by grinding in sand. All portions were filtered through two folds of nylon cloth. All materials were maintained at 0 to 4°C under aseptic conditions. Organelle isolations were completed within 5 h of harvest, without freezing the preparations. The combined filtrates from a sample were centrifuged at 100 g for 2 min in a Sorvall RC-2B centrifuge using an SS-34 rotor, and the pellet was resuspended in isolation medium for subsequent analysis. The supernatant from the 100 g separation was centrifuged at 1,000 g for 10 min, and the pellet from that centrifugation was resuspended in the same manner as the 100 g pellet. This procedure was repeated at 10,000 g for 20 min, and the next fraction was obtained by pelleting the remaining particulate matter by centrifuging the supernatant of the 10,000 g separation in a Spinco Model E ultracentrifuge for 2 h at 94,000 g; the supernatant fluid from this 94,000 g centrifugation was termed the soluble fraction. Triton X-100 was added to these fractions before the enzyme activity determinations to solubilize lipids.

Organelle Identification. Portions of all organelle fractions were stained with I_2-KI solution to test for starch, zinc-chloriodide for cellulose, Janus Green for mitochondrial activity, and Feulgen-stained to test for nuclear material (Koch, 1973); all fractions were examined using a light microscope at 400X magnification before the addition of Triton X-100. Intact chloroplasts were identified without staining, and the extent of chloroplast destruction was estimated by chlorophyll analysis (Bruinsma, 1963), after the addition of 4.0 ml of acetone to a 1.0 ml aliquot of the sample.

Protein Determination. The precipitate remaining after the acetone extraction of chlorophyll was removed by centrifugation and stored at -20°C until required for protein analysis. One-half ml of 1 N NaOH was added to the residue and the mixture was incubated 80°C for 1 h, with occasional stirring. The resulting protein extract was assayed using the method of Lowry, et al. (1951), with bovine serum albumin as the protein standard. The protein content of the Sephadex eluate was estimated from the absorbance at 280 nm.

Enzyme Assays. One-half ml of enzyme preparation was added to 1.5 ml of 0.4% yeast RNA in acetate buffer for the RNase assay, or 0.4% calf thymus DNA in buffer for the DNase analysis and incubated for 1 h at 35°C. The reactions were stopped using 2 ml of a stop solution consisting of 0.3% LA $(NO_3)_3$ in 2.5% trichloracetic acid. Single-stranded DNA was prepared by incubating the DNA solution at 90°C for 1 h, and plunging it in ice. All nuclease activities are expressed in the units recommended by Wilson (1975).

The assay system for phosphodiesterase activity contained 1 μmol of bis(p-nitrophenyl) phosphate, 100 μmol buffer, and 0.3 ml of enzyme preparation in a final volume of 2.0 ml. The reaction was stopped with 1.0 ml of 0.3 M NaOH, and the increase in absorbance at 400 nm due to the liberation of p-nitrophenol was measured. All substrates were obtained from Sigma Chemical Co., St. Louis, Mo., U.S.A.

RESULTS

Attached Leaflets. The RNase activities of crude homogenates were distinguished by pH optima at 4.8, 6.0, and 6.4 (Fig. 1). The pH optima were unchanged during the enzyme purification process, and the shoulder at pH 5.4 appeared as a separate but low activity, RNA-specific enzyme after gel filtration (Fig. 2 and Table 1).

When leaflets were fractionated, and the pellets resuspended in isolation medium, the 100g fraction contained cell wall material, some starch, and most of the nuclei; the characteristics of the 100g fraction are discussed elsewhere (Dove and Oduola, 1980). Most chlorophyll and the intact chloroplasts were found in the 100g to 1,000g fraction. The 1,000g to 10,000g fraction contained a large number of membrane-bound, but unidentifiable bodies, as well as mitochondria. Fractions sedimenting at higher forces were examined with the light microscope, but the particles could not be identified. No pH 5.4 activity was detectable in any of the fractions before the detergent Triton X-100 was added. Treatment of the mitochondrial fraction with Triton X-100

Table 1. Some characteristics of the major peaks having RNase activity, separated by Sephadex G-75 gel filtration.

Peak	pH Optimum	Substrate Specificity
I	4.8→5.0	RNA
II	5.4→5.6	RNA
III	6.0	RNA
IV	6.2→6.4	RNA and DNA (phosphodiester bonds)
V	6.2→6.4	RNA and DNA (Phosphodiester)

increased the RNase activity of the pH 4.8 enzyme and also resulted in RNase activity at pH 5.4 The soluble fraction had considerable activity of both types after the Triton X-100 treatment. The pH 5.4 enzyme activity was found exclusively in the mitochondrial and soluble fractions (Table 2), while the pH 4.8 activity was also found in the 10,000g to 94,000g fraction.

Detached Leaflets. Leaflets floated on water for 24 h had higher RNase activities of the pH 4.8 and 5.4 types (Fig. 3) than attached controls (compare Figs. 2 and 3). The organelle isolation procedure revealed that the pH 5.4 activity remained restricted to the mitochondrial (1,000g to 10,000g) and the soluble (>94,000g) fractions (Table 2). No differences in appearance were found between the fractions from detached leaves and those from attached leaf controls.

Table 2. Effects of detachment on the RNase activity of subcellular fractions assayed at pH 5.4, with Triton X-100 included in the assay mixture.[a]

	Attached leaves		Detached leaves	
Fractions	Total Units	Units mg^{-1} Protein	Total Units	Units mg^{-1} Protein
100g	0	0	0	0
100 to 1,000g	0	0	0	0
1,000 to 10,000g	17.8	1.1	81	7.5
10,000 to 94,000g	0	0	0	0
soluble	347	20.9	1480	26.1

[a]No activity of pH 5.4 is detectable in any fraction from attached leaves, unless Triton X-100 is included in the assay mixture.

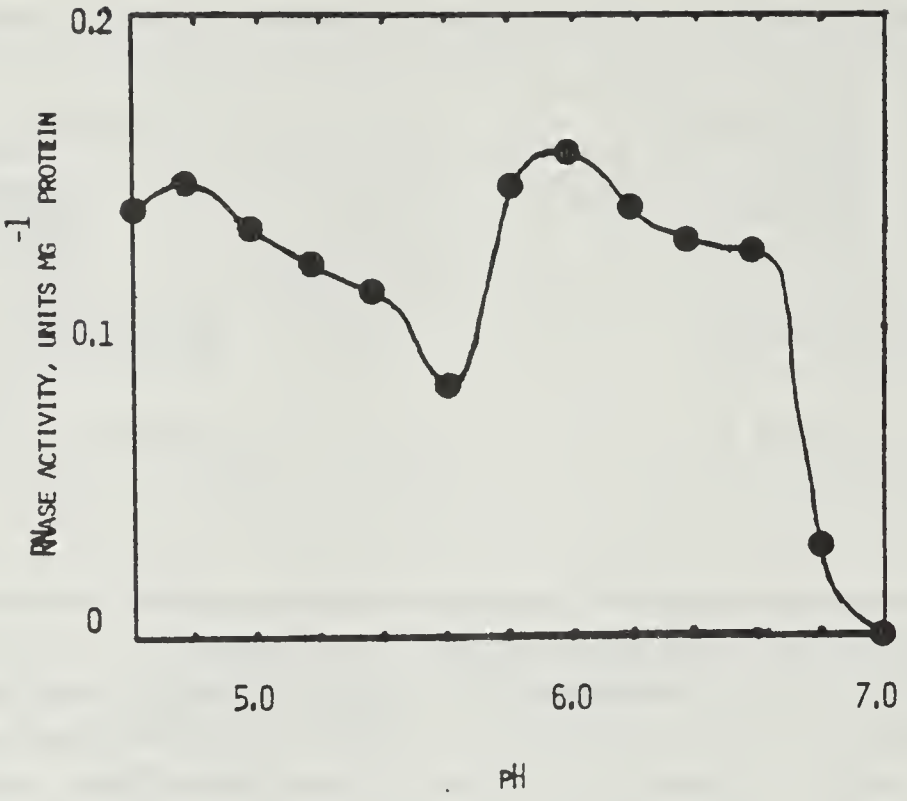

Fig. 1. Effect of pH on the RNase activities of a crude homogenate from 10 g of leaflets.

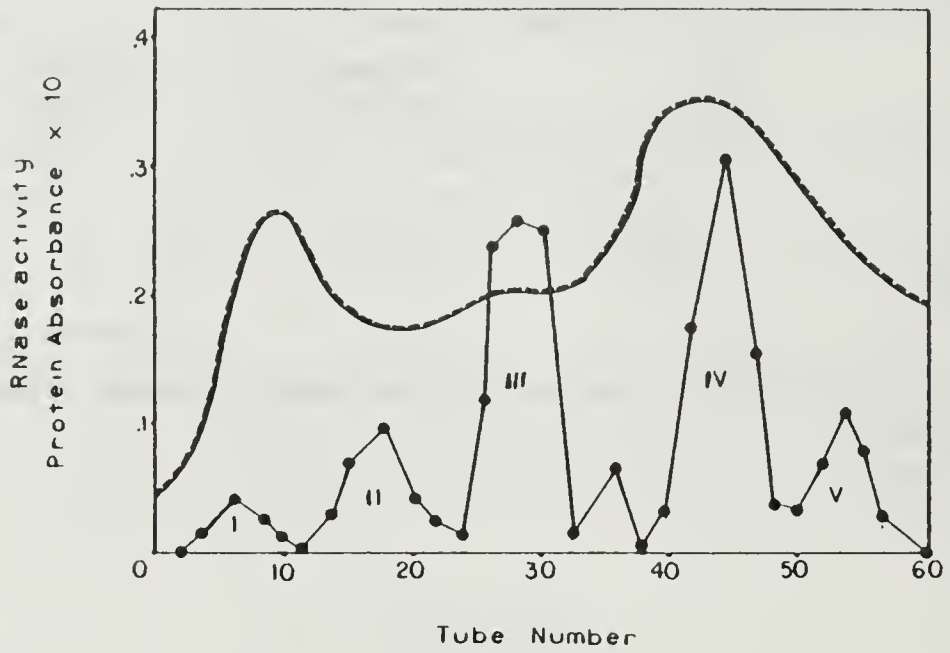

Fig. 2. RNase and protein distribution in the .05M Tris (pH7.5) eluant from a Sephadex G-75 column, following application of a dialyzed 20-80% $(NH_4)_2SO_4$ preparation from 30g of leaflets. RNase assay at pH 6.2 ——RNase,– – –protein.

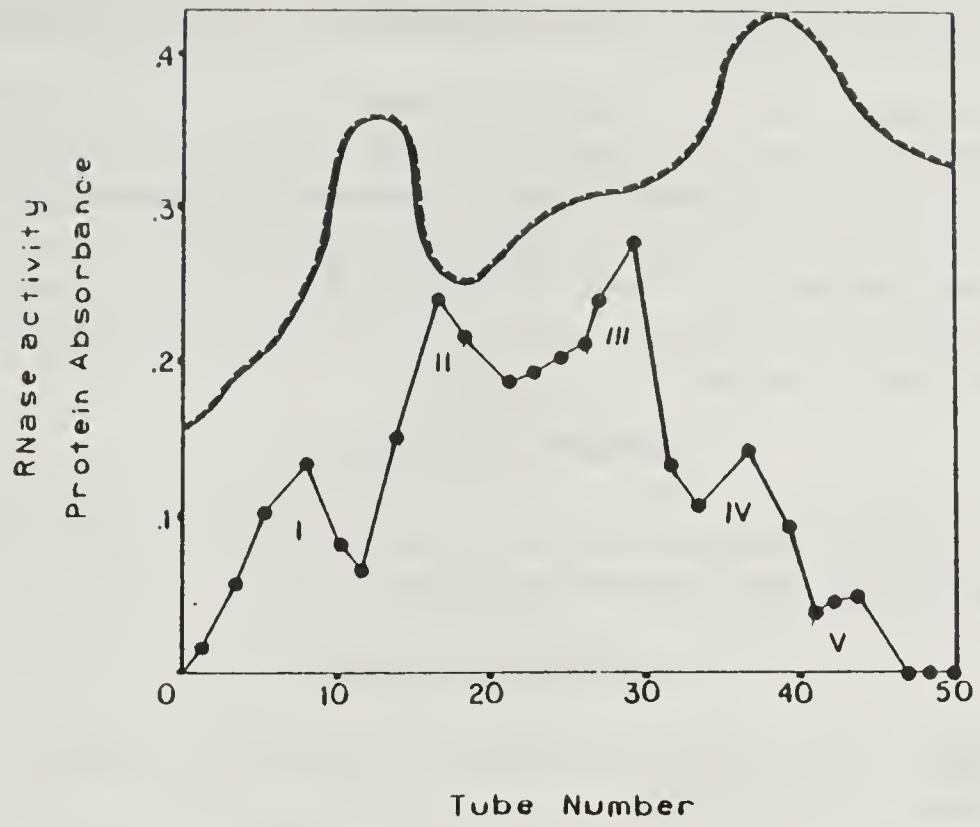

Fig. 3. RNase and protein distribution in the .05M Tris (pH7.5) eluant from a Sephadex G-75 column, following application of a dialyzed 20-80% $(NH_4)_2SO_4$ preparation from 30g of leaflet blades previously detached and floated on water for 24 h. RNase assay at pH 6.2 ——RNase, – – –protein.

CONCLUSIONS

An RNase is produced in response to blade detachment at a time when protein granules appear in the central vacuoles of tomato mesophyll cells, and membrane-bound bodies are fusing with the tonoplast (Shumway, et al., 1970; Matile, 1975). The RNase is membrane-bound in bodies which pellet in gravitational fields ranging from 1,000g to 10,000g. It has a pH range of 5.4 to 5.6, and is easily solubilized using the detergent Triton X-100. Other enzymes having RNase activity are present, but their subcellular distribution is not well defined, except for a pH 6.4 nuclear enzyme described in another paper (Dove and Oduola, 1980).

ACKNOWLEDGEMENTS

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VERTEBRATE REMAINS FROM EARLY EUROPEAN AND HISTORIC INDIAN OCCUPATIONS AT THE WATERMAN SITE, RANDOLPH COUNTY, ILLINOIS

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ABSTRACT

Excavation of portions of the Waterman site in 1971, a former Indian village in Randolph County, Illinois that was occupied by the Michigamea and Kaskaskia, yielded ca. 4900 remains of at least 38 vertebrate species. Aboriginal occupation of the area was directly associated with Fort du Chartres, a fort built by the French in 1720 and later occupied by the British from 1765 to 1772. The Indians had relied heavily on the white-tailed deer as a major meat staple in their food economy, with a variety of smaller mammals, aquatic turtles, and fish serving as important diet supplements. Several features and a house structure at this site represented a later (ca. 1820-40) farmstead; remains of pig dominated the faunal remains from this period.

INTRODUCTION

The animal remains examined during this study were recovered at the Waterman site in September and October, 1971, by an archaeological field crew under the direction of Dr. Margaret K. Brown. Excavations were carried out in the village area, once occupied by the Michigamea and Kaskaskia, which is located ¼ mile north of the present Fort du Chartres. The fort was built by the French in 1720; however, because of damage due to flooding by the Mississippi River, it was rebuilt in 1727. The third and final construction (of stone) at a more favorable location was completed in 1756 and the fort remained in French hands until British troops took possession in October, 1765. It was then renamed Fort Cavendish and served as the seat of British government in the Illinois Country until it was abondoned and destroyed in 1772.

Bone was encountered in the plow zone, 12 houses, and in 17 features that were recognized as having been a part of the general village area occupied by Indian groups. Cultural materials found in these houses and features, especially the European trade goods (glass beads, copper, lead, ceramics, silver), indicate that the accumulation of associated faunal debris resulted from animals that had been used by Indians (Table 1). Animal remains from House 8 and features 34, 36 and 67 (Table 2), however, represent refuse that is thought to have come from a later (ca. 1820-40) farm in the area. A total of approximately 32 native species were represented in the sample, including 5 fish, 1 amphibian, 10 birds and 11 mammals. Canid remains from six of the houses and four features probably represent Indian dogs which were apparently associated with the village settlement. At least seven dogs were represented, three of which were pups with deciduous dentition. Elements of four domestic animals (chicken, cow, horse, pig) were recovered in the faunal sample, but only 22 pieces (17 cow, 2 pig, 3 horse) occurred in features associated with Indian occupation. Although the Indians may have had their own domestic stock, or on occasion received animals kept by the European inhabitants, these few remains (like *Rattus* and the house mouse in House 8) may be intrusive in the features. A total of approximately 3600 bone pieces from the aboriginal occupation, and 1300 from the early farmstead were examined.

SPECIES UTILIZATION

Bones of the white-tailed deer occurred in all 12 houses and in 14 of the 17 features. At least 20 indivduals were represented; in addition to the 689 elements specifically identified as deer, approximately 1,500 unidentifiable large mammal bone fragments were also probably of this animal. A ca. 2-month old fawn from house 15 and a ca. 3 to 4-month old fawn from House 14 suggest that these structures were occupied at least during the middle-to-late summer period. The frequency of deer bone throughout the excavated areas of the village site reflects the animal's significance to these people as a basic source of food, undoubtedly hides, and to a lesser extent bone and antler for the manufacture of utensils and other objects. The deer meat staple was supplemented with a variety of other species such as the bowfin, both aquatic and terrestrial turtles, raccoons and muskrats. The black bear would have also provided a considerable quantity of meat, but judging from the relatively small number of elements recovered (25 pieces, 3 indivduals) during the 1971 excavations at Waterman, the animal apparently was taken only occasionally.

A similar limited use of several other mammalian species may be noted. The occurrence of cougar remains (scapula) and those of the bobcat (humerus, radius, ulna) in Feature 67 is of interest, although the use made of these felids is not evident from these unmodified elements. Like most of the other terrestrial species represented by one or a few individuals, they were probably taken in relation to availability. Recovery of only three pieces of beaver bone, an innominate section from Feature 37 and lower jaw and skull section from Feature 47, is surprising in light of the animal's known value to nearly all Indian groups as a source of meat and furs. Possibly the local beaver populations had already been depleted by trappers. Suitable haitat for these large aquatic rodents was present as evidenced by the recovery of muskrat elements in House 10 and Features 7, 37, and 67. At least four muskrats were represented in Feature 37.

Butchering and/or skinning cuts were noted on several elements. Scored white-tailed deer bones included 2 distal humeri (severing the forelimb at the ''elbow''), 1 distal tibia (removal of the hind foot at the hock), and 1 scapula (separating the shoulder at the head or proximal end of the humerus); 1 proximal metacarpal, 1 distal metatarsal, 1 sternabra, and 2 carpals exhibited knife marks which may have resulted from the skinning operation rather than from dismemberment of the carcass. The skull section of a large buck found in Feature 8 still had the antlers attached although the left beam had been chopped off about six inches from the base (skull). A section of a large antler beam recovered in Feature 69 had been cut off at the base. Scored marks occurred on the distal end of a muskrat tibia, inflicted during removal of the hind foot. It is of interest to note that a canid (dog?) cervical vertebra from House 13 and ulna and distal tibia sections from House 10 bore knife marks. This evidence suggests that dogs were butchered and eaten on occasion.

Birds played a negligible part in the subsistence of these people, judging by the paucity of avian material in this sample. Only eight species were identified, and, except for remains of two individual ducks associated with Feature 47 and from the plow zone, no more than one individual of each was represented. Combined, bird bones totaled less than one percent of all elements recovered.

The meager quantity of avian bones from the Waterman site is surprising, considering the variety of species and the number of birds that would have been available to these people, especially waterfowl, during migrations. An interesting contrast in the exploitation of an avian food resource by another historic Indian group (Sauk-Fox) may be noted in the variety of species and quantity of bird remains reported from the Crawford farm Site, Rock Island County, Illinois (Parmalee 1964). This village site, situated near the confluence of the Rock and Mississippi rivers, was occupied ca. 1790-1810. Although bird elements (172 identified pieces) constituted only 3 percent of the total sample, there were at least 28 species represented. The occupants of the Michigami village appear to have been either little interested in birds as a source of food, or else they may have been absent from the village during the spring and fall bird migrations. The lack of turkey bones in the sample (the turkey would have been available throughout the year) also points to a possible general disinterest in birds as a food resource.

There were approximately 10 unidentifiable bird bone pieces, four of which had been cut, drilled, scraped or otherwise modified as a tool or ornament. One element, a proximal ulna section of a trumpeter swan which had been cut off by the "groove-and-snap" technique, occurred in Feature 54. Ends of humeri, ulnae, and radii of large birds (e.g. swans, geese, cranes) and occasionally limb elements of mammals were often removed in this fashion and the shaft sections were then modified for use as whistles, special tubes, or for other decorative purposes (Parmalee 1976). Since only the modified shaft portions of the other four worked bird bones were recovered (1 from House 5 with four incised grooves at one end; 1 from House 8 with two incised grooves and four drilled holes at one end), specific determinations could not be made. In spite of the apparent little use of birds as a food supplement, wing bones of large species appear to have been desirable for the manufacture of implements.

The species of fish and aquatic turtles identified from the Indian features are indicative of backwater lakes and sloughs, and it appears that these habitats, rather than the main river channel, were a source of these animals. Although a few buffalo and catfish were taken, the bowfin appears to have been the preferred species; 210 elements of *A. calva* occurred in Feature 69, representing at least seven individuals. Considering the total size of the faunal sample (number of remains and individuals), turtles were of importance as an occasional food supplement in the diet. Large red-eared turtles (*Chrysemys* cf.*scripta*) appear to have been especially prized, although remains of the smaller painted and box turtles were numerous. Aquatic species were the most important. There were at least 65 individuals represented in the Waterman site faunal sample and the number of pieces of turtle shell and bone comprised 20 percent of the total. Turtle remains occurred in 6 of the 12 houses and in 7 of the 17 features. None of the carapace sections bore evidence of having been modified (cut and/or scraped) for use as a bowl or dish, so the use of turtles appears to have been only for food. A plastron section and coracoids from two snapping turtles exhibited butchering cuts. It is of interest to note that no turtle elements were found in the early American structures/features (Table 2).

Freshwater mussels could have served as another easily accessible source of food, but only two unmodified valves were recovered. A right valve of the pocketbook *(Lampsilis ovata)* occurred in House 14 and a left valve of the black sandshell (*Ligumia recta),* was found in Feature 47. An axis section of a small marine gastropod (House 10) was the only other mollusk encountered in the excavations.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. Margaret K. Brown for providing us with the opportunity to examine the Waterman site faunal assemblage and for her patience in supplying relative excavation and site data. Appreciation is extended to the Illinois Department of Conservation which provided funds for excavation and analysis of the Waterman site material.

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Table 1. Vertebrate remains from Indian structures/features at the Waterman Site, Illinois.

Species	No. of pieces	%	Min. no. individ.	% MNI
FISHES	461	12.83	36	21.95
Gar, *Lepisosteus* sp.	6	.17	1	.61
Bowfin, *Amia calva*	344	9.57	23	14.02
Buffalo, *Ictiobus* sp.	10	.28	2	1.22
Buffalo/Sucker: Catostomidae	4	.11	2	1.22
Catfish/Bullhead, *Ictalurus* spp.	35	.97	8	4.88
Indet. fish bones	62	1.73	—	—
REPTILES (TURTLES)	734	20.43	65	39.63
Snapping Turtle, *Chelydra serpentina*	44	1.22	9	5.49
Eastern Box Turtle, *Terrapene carolina*	5	.14	4	2.44
Box Turtle, *Terrapene* sp.	66	1.84	14	8.54
Painted Turtle, *Chrysemys picta*	25	.70	11	6.71
Red-eared Turtle, *Chrysemys* cf. *scripta*	127	3.53	26	15.85
cf. Map Turtle, *Graptemys* sp.	2	.06	1	.61
Turtle: *Chrysemys/Graptemys* group	411	11.44	—	—
Indet. Turtle Bone	54	1.50	—	—
BIRDS	28	.78	10	6.10
Trumpeter Swan, *Olor buccinator*	1	.03	1	.61
Mallard/Black Duck/Pintail, *Anas* sp.	1	.03	1	.61
cf. Blue-winged Teal, *Anas discors*	1	.03	1	.61
cf. Redhead, *Aythya americana*	3	.08	1	.61
Duck spp.	7	.19	2	1.22
Golden Eagle, *Aquila chrysaetos*	1	.03	1	.61
King Rail, *Rallus elegans*	1	.03	1	.61
cf. Common Snipe, *Capella gallinago*	1	.03	1	.61
Passenger Pigeon, *Ectopistes migratorius*	3	.08	1	.61
Indet. Bird Bones	9	.25	—	—
MAMMALS	2370	65.96	53	32.32
Opossum, *Didelphis marsupialis*	1	.03	1	.61
Black Bear, *Ursus americanus*	25	.70	3	1.85
Raccoon, *Procyon lotor*	23	.64	7	4.27
cf. Dog, *Canis familiaris*	49	1.36	7	4.27
Cougar, *Felis concolor*	1	.03	1	.61
Bobcat, *Lynx* cf. *rufus*	4	.11	1	.61
Beaver, *Castor canadensis*	3	.08	1	.61
Marsh Rice Rat, *Oryzomys palustris*	1	.03	1	.61
Muskrat, *Ondatra zibethica*	37	1.03	7	4.27
White-tailed Deer, *Odocoileus virginianus*	689	19.18	20	12.20
Cow, *Bos taurus*	17	.47	2	1.22
Pig, *Sus scrofa*	2	.06	1	.61
Horse, *Equus caballus*	3	.08	1	.61
Indet. Mammal Bones	1515	42.17	—	—
Totals	3593	100.00	164	100.00

Table 2. Vertebrate remains from early American structures/features at the Waterman Site, Illinois

	House 8	Fea. 34	Fea. 36	Fea. 67	Total no.of pieces	%	MNI
FISHES					405	31.15	20
Smallmouth/Black Buffalo, *Ictiobus* sp.				14	14	1.08	1
Buffalo, *Ictiobus* sp.	7				7	.54	1
Black Bullhead, *Ictalurus melas*	1				1	.08	
Brown, Bullhead, *Ictalurus nebulosus*	14				14	1.08	
Bullhead, *Ictalurus* sp.	368				368	28.31	18*
Indet. Fish Bones			1		1	.08	—
AMPHIBIANS					1	.08	1
Eastern Spadefoot, *Scaphiopus holbrooki*	1				1	.08	1
BIRDS					92	7.08	9
Trumpeter Swan, *Olor buccinator*			3		3	.23	1
Mallard/Black Duck/Pintail, *Anas* sp.			39		39	3.00	3
cf. Green-winged Teal, *Anas crecca*			1		1	.08	1
Duck sp.			12		12	.92	—
Domestic Chicken, *Gallus gallus*	4		5	2	11	.85	3
cf. Redwinged Blackbird, *Agelaius phoeniceus*			1		1	.08	1
Indet. Bird Bones			24	1	25	1.92	—
MAMMALS					802	61.69	
Raccoon, *Procyon lotor*				1	1	.08	1
Squirrel, *Sciurus* sp.			3		3	.23	2
Eastern Cottontail, *Sylvilagus floridanus*			4	4	8	.62	2

Rat, *Rattus* sp.	1				1	.08	1
House Mouse, *Mus musculus*	1#				1	.08	1
White-tailed Deer, *Odocoileus virginianus*			4	1	5	.38	2
Cow, *Bos taurus*	1	1		1	3	.23	1
Pig, *Sus scrofa*	29		141	86	256	19.69	14
Indet. Mammal Bones			430	94	524	40.31	–
Totals	427	1	668	204	1300	100.00	54

*MNI, all bullheads, House 8
#Complete skeleton

MICROCOMPUTER INTERFACE WITH TV

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INTRODUCTION

The cost of CRT monitors justifies an analysis of TV monitor based terminals. The CRT controllers used in the terminal interface are LSI (Large Scale Integration) components and can be programmed for use with TV monitor interface with the microcomputer systems. An important aspect of TV monitors is the need for an external mixer interface circuit while CRT monitors include mixer circuits for producing composite video signals. This paper describes a mixer circuit to implement a TV monitor interface for 8080 based microcomputer systems.

HARDWARE

It consists of a basic computer system, DMA (Direct Memory Access) controller (Intel 8257), CRT controller (8275), Interrupt controller (8259), Octal keyboard, ASCII keyboard, Dot timing logic, Mixer circuit, and a TV monitor (Fig. 1).

The basic system, (Fig. 2), is implemented using an 8080 microprocessor and 4K bytes of memory. The first four pages (256 bytes/page) are implemented with PROM (Programmable Read Only Memory) for utility programs and the following four RAM (Random Access Memory) pages are used for user-oriented programs. The last eight RAM pages are used as display memory. The basic interface functions of the processor are to service the octal keyboard for bootstrapping a user-oriented program in the RAM part of the program memory, to service the ASCII keyboard for loading characters into the display memory, to intialize the peripheral devices, and to reinitialize the DMA controller at the end of every frame of TV display in interrupt mode. The interrupt request lines from the devices are interfaced with an 8259 such that the DMA controller has the top priority. Whenever one or more devices require service, the interrupt controller will resolve the priority, and switch the processor into the appropriate service routine.

Video terminals may utilize either a software display technique (character display) or a hardware controller technique (row display). In the character display technique, the processor is used as a controller eliminating some of the complex interface circuits. The disadvantage of this technique is that the processor is tied up with the display controller operation thereby reducing the data throughput capability of the system. The system described in this paper uses the row display technique (Fig. 3). The basic function of the DMA controller is to put the processor in the HOLD mode and to transfer the display characters from the memory to the CRT controller through the common buses. The operation sequence of the DMA controller is called a DMA cycle and is executed for each display character. The DMA cycle sequence is that when the CRT controller requests data (DRQ), the DMA controller puts the cpu in the HOLD mode, generates the programmed memory address and device select pulses, reads the memory and strobes the display character code into the CRT controller. The MEMR signal drives the MEMR of the memory for reading the data and I/ow signal drives the WR signal of 8275 for strobing the data.

The functions of the 8275 CRT controller include refreshing the TV display by buffering information from display memory and generating horizontal and vertical timing signals for TV synchronization. Visual attribute features allow the implementation of specialized graphic display functions and display enhancement operations. The 8275, having been programmed for a specific screen format, generates a series of DMA (DRQ) request signals which result in the transfer of a row of characters from display memory via the 8275's row buffers. The 8275 presents the character codes to the TV monitor through the dot timing logic and mixer circuits as in Fig. 4. The character code outputs CCO-CC4 are applied to the character generator address line A3-A7. Line count outputs LCO-LC2 from the 8275 are applied to the character generator address lines AO-A2. It should be noted that the 8275 displays character rows one line at a time. The line count outputs

are utilized to determine which line of the character selected by A3-A7 will be displayed. Following the transfer of the first line to the dot timing logic, the line count is incremented and the second line of the character row is selected. The process continues until the last line of, the row under consideration is transferred to the dot timing logic. The row by row transfer of character data from display memory to the 8275 continues until the beginning of the last display row. At this time the 8275 issues an interrupt (IRQ) to the 8259. The cpu is then switched into the interrupt service routine to reinitialize the 8257 DMA controller starting address and terminal count parameters. Interrupts are generated by the 8275 every 16.67 ms for a 60HZ screen refresh rate.

One function of the dot timing logic is to transfer display characters synchronously to the TV monitor. Synchronization is achieved by dot and character clocks. These clocks are generated by the processor's clock generator. The dot and character clock frequencies are interrelated and are dependent upon the TV's horizontal oscillator repetition rate and display character width. The clock frequency of the system is 16.81 MHZ and this will fix the dot and character clocks at 8.405 MHZ and 1.2 MHZ respectively as shown in Fig. 4. The display character from the ROM is in parallel mode, whereas the TV monitor requires characters in serial form. The parallel to serial shift register (74166) performs this required mode conversion. The character clock loads the parallel data into the 74166 register and the dot clock shifts the loaded data to the TV monitor. The response time of the 8275 and ROM will be too long to reliably latch the ROM output for the first display character during the first character clock period. This situation is eliminated by introducing the 74175 between the 8275 and the ROM. The 74175 latches the character codes and line counts 1/2 character clock after the positive-going edge of the character clock and loading ROM data into the 74166 shift register on the next positive-going edge of the character clocks. This pipelining technique delays the video output from the shift register by 1 1/2 character clocks, but eliminates the difficulties in sampling the ROM data within the first character clock period.

Due to the video delay associated with the pipelining technique, the dot timing logic delays all the raster signals (HRTC and VRTC) and the video control signals (VSP, RVV, and LTEN) using a two-stage shift register constructed with edge triggered D flip-flops (74175), Fig. 5. The synchronized video signal is then dot-widened by the use of 74LS32 OR-Gates. The contents of display memory may be display or visual and special character codes. The visual attribute characters are classified into character and field attribute types. The display character codes can be used to generate graphic symbols without the use of the character generator. This is accomplished by selectively activating the Line Attribute outputs (LA_{0-1}), the Video Suppression output (VSP), and the Light Enable output. The dot level timing circuitry can use these signals to generate the proper symbols as shown in Fig. 6.

The final stage of interfacing is to combine the video signal with the delayed raster timing signals (HRTC and VRTC). This is achieved by means of CMOS analog switches (4066)-based mixer circuit as in Fig. 7. The switch is enabled only when HRTC, VRTC, and DOT widened video are all active. The composite video signal is then connected to the second detector of the TV circuit.

SOFTWARE

The DMA, CRT, and Interrupt controllers are intelligent devices, therefore they must be programmed for the required data communication functions. The device-select-pulses for peripherals are generated by 8205 as shown in Fig. 3.

The device numbers OXH, 1XH, 2XH, 3XH, and 4XH are assigned to 8259, 8275, Octal keyboard, ASCII keyboard, and 8257 respectively. Upon power up, the initialization routine is executed. At the beginning of this routine, the interrupt controller is programmed so that the interrupt traps start with the memory location 000 140_8. The next step in the initialization routine is to program the CRT controller. This begins with a reset command followed by four parameter commands. The parameter commands are for Screen-composition information such as spacing, row length, VRTC length, frame size, position of the underlining, lines per row, and the size of HRTC. The selection of dot clock, HRTC, and the frame size must be within the horizontal repetition rate

(15,970 ± 500 pps) of the TV monitor. For 8.405 MHZ of dot clock, 28 CC1ks (character clocks) of HRTC, 49 characters per row, and a character width of 7 dots, the horizontal oscillator repetition rate is determined as follows:

$$f_{Horiz.} = 8.405 \times 10^6 / ((28 \pm 49) \times 7) = 15{,}594 \text{ pps.}$$

This value is within the tolerance range of the TV monitor value. The VRTC is programmed to be 2 to satisfy the 60 HZ refresh rate and 24 rows of frame size. The final step in the 8275 programming is to load the cursor position command followed by a start display command. The start display command includes the burst size and burst space for DMA operation.

Finally, the initialization routine blanks the complete display memory, defines intermediate data storage positions for the pointer for display memory and cursor position, enables interrupt, and puts the processor in the halt mode for peripheral interruption. The listings of the initialization and service routines are given in Figs. 8 to 11.

The octal keyboard is used for boot-strapping user programs in object code in the program memory ($004\ 000_8 - 007\ 377_8$). The processor is interrupted and switched into the octal keyboard service routine for every octal key press. The sequence for program loading with the octal keyboard starts with the selection of program location. This is done by the use of H, L, and numeric keys. In the chosen program address, the instructions are stored by the use of numeric and S keys. Instructions are stored one byte at a time and the storage of each byte requires the use of three numeric keys and the storage key, S. At the end of the service routine, the interrupt status prior to the interruption of the processor is re-established.

The DMA refresh routine, Fig. 10, is located at the third page ($002\ 000_8$) of the memory map. In this routine, the interrupt request from 8275 is disabled and the DMA controller is loaded with the address of display memory and the terminal count. The DMA controller is then programmed to be in the autoload mode and the interrupt of 8259 is reset to complete the refresh routine. At the end of every frame of display, the 8275 generates an INTR signal requesting processor interrupt service for DMA refresh. When the INTR signal is active, the 8259 generates an INT signal to switch the processor into the DMA refresh routine. The starting location of program memory is incremented by the number of characters in a row (49) and at the end of every frame as required by the scrolling operation. The DMA refresh routine can be eliminated from the solftware if scrolling operation is not required.

The ASCII keyboard routine, Fig. 11, is located at the second page ($001\ 000_8$) of the memory. It is used for screen control and loading display memory. This routine is serviced by the processor for every ASCII-key press. There are three types of ASCII keys. They are normal display, attribute, and control keys. The control keys are used for screen control operations such as back space, tab, line feed, and escape. These keys do not occupy any character position in the display memory and therefore they are not processed by 8275. These control operations are performed by the processor using dedicated subprograms located at $001\ 134_8$, $001\ 151_8$, $001\ 166_8$, and $001\ 047_8$. The normal display codes are loaded in the display memory so that they are displayed under the control of 8275. Attribute keys are classified into field and character codes. The key codes from the encoder of the keyboard are not in standard format and therefore the processor performs code-conversion operation using a look-up table ($001\ 232_8$) before storing these characters in the display memory. A detailed analysis of the ASCII keyboard service routine will reveal that whenever a screen control operation is performed or a code is loaded in the display memory, the cursor position, the character and row counters, and the memory pointer are assigned with the proper value to enable proper screen scrolling operation.

CONCLUSION

A resident assembler can be included in the system with the addition of 4K bytes of memory. Options such as Light Pen Detection and General Attributes can be easily implemented by the addition of simple control logic circuit to the proposed interface. The TV and CRT monitor—based terminals will have identical graphic features if they are implemented with the same monitor controller (8275). The only disadvantage of the TV monitor-based terminals is that they can handle only about 49 characters per row. In applications, hobby market in particular, where the screen size is not a major factor, cost reduction can be achieved by replacing the high cost CRT monitors with the cheaper TV monitors without sacrificing other graphic characteristics.

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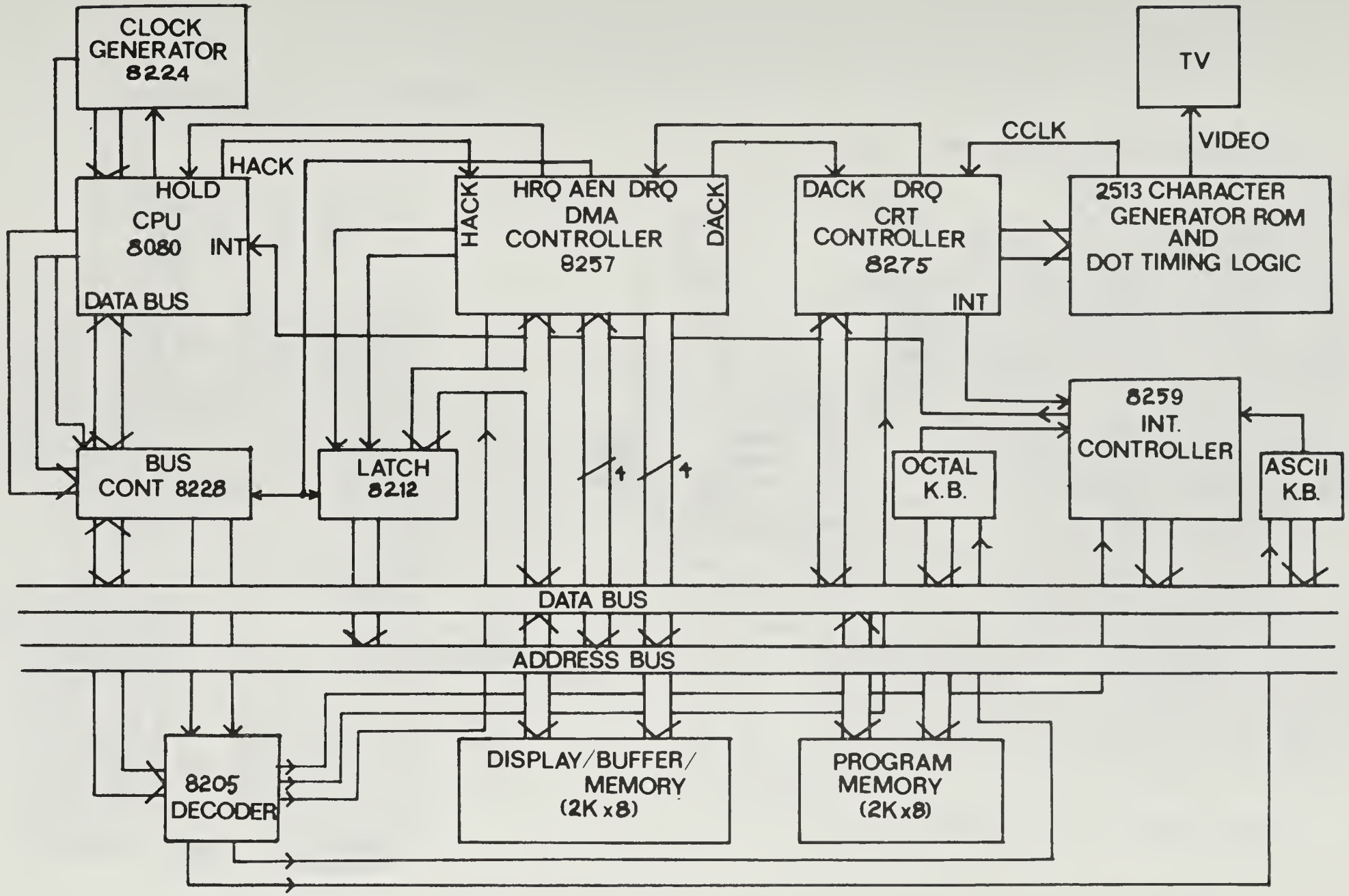

FIG. 1 MICROCOMPUTER SYSTEM — TV MONTOR

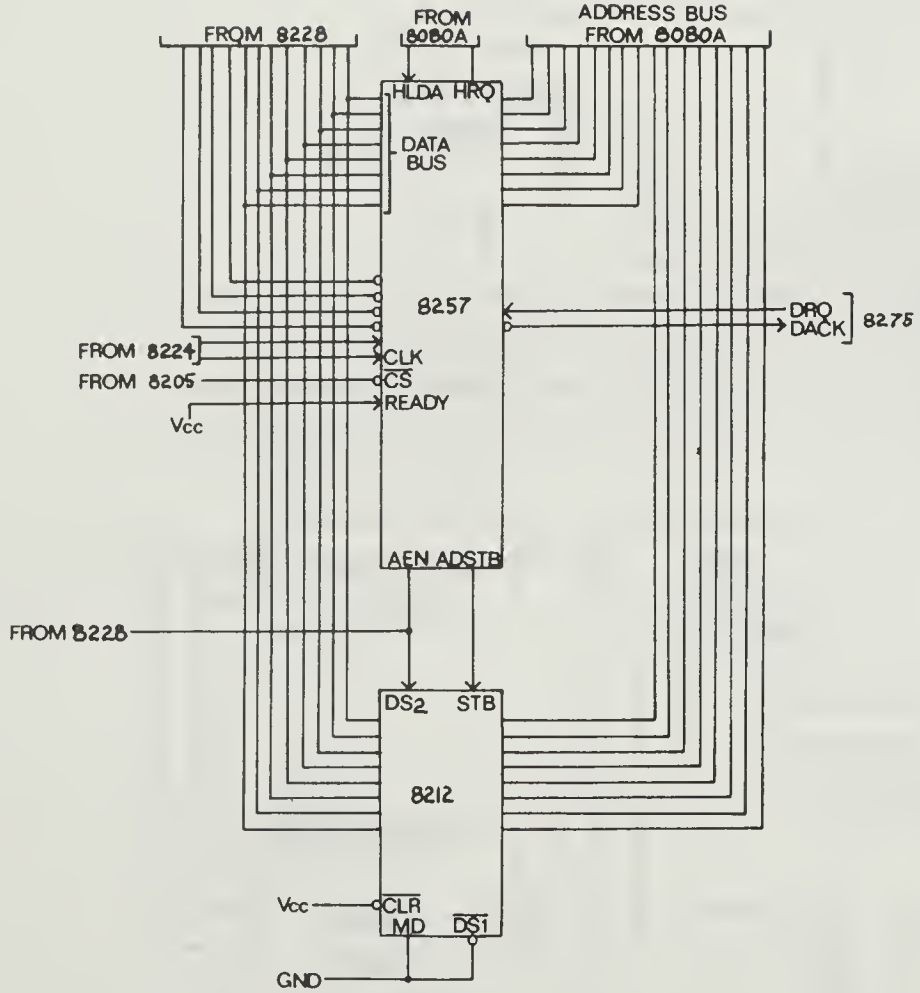

FIG.2 8080 BASIC SYSTEM WITH 8257 AND 8259 (CONTD.)

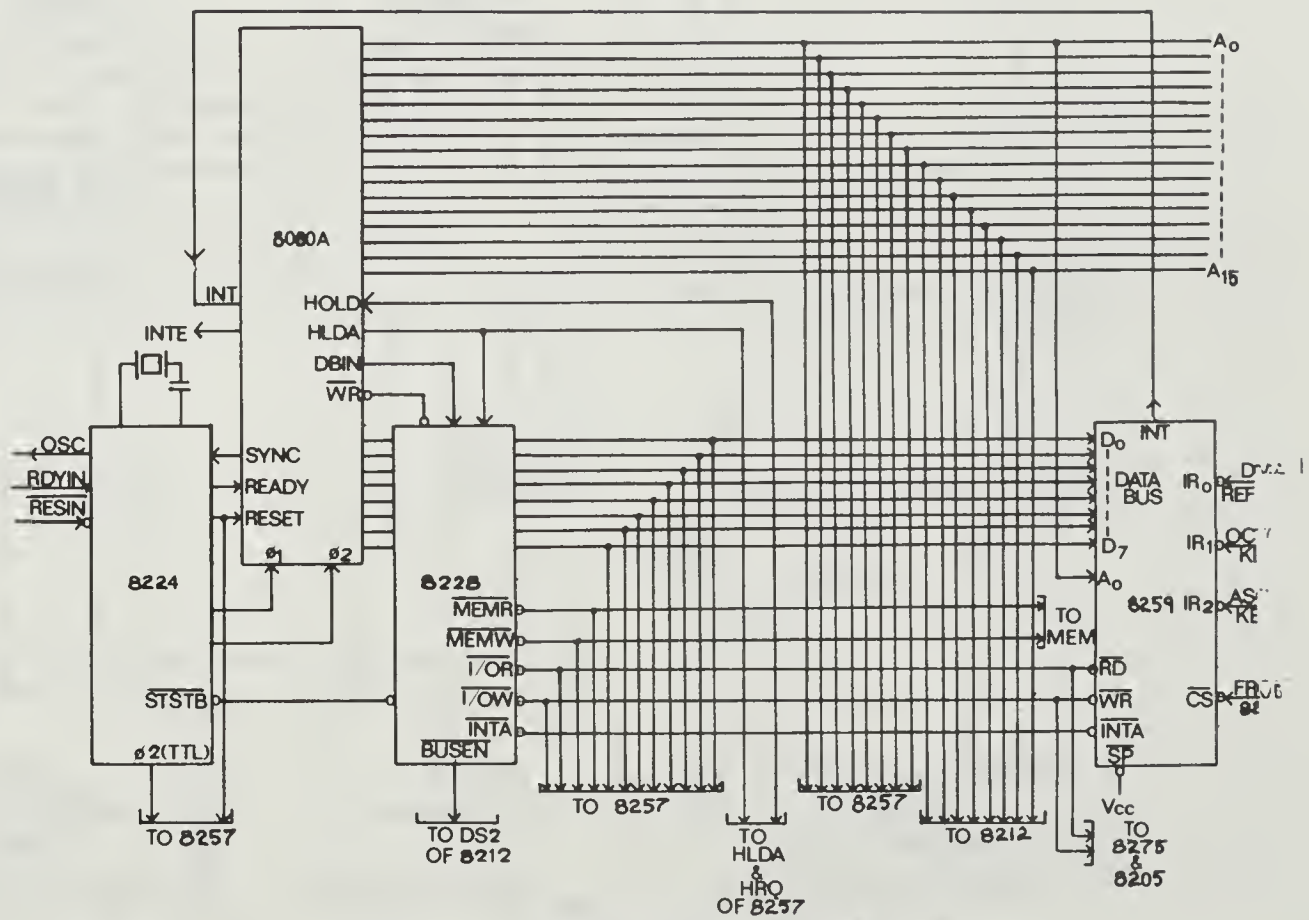

FIG.2 BASIC SYSTEM WITH 8257 AND 8259

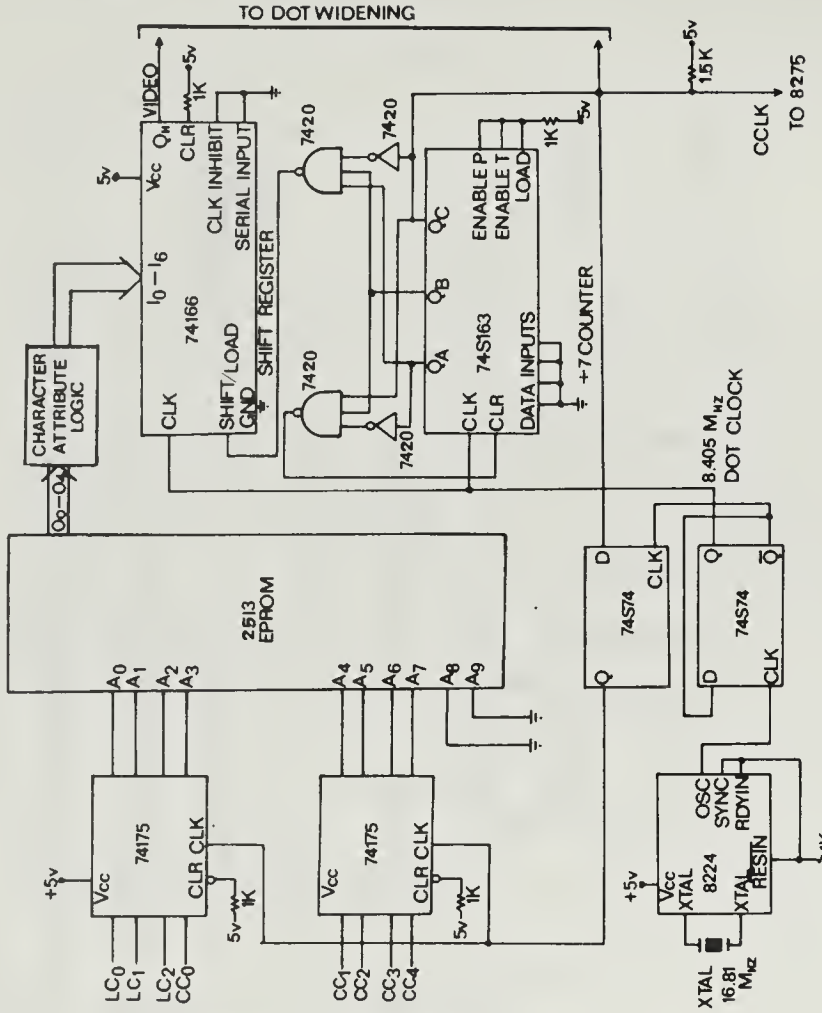

FIG.4 DOT TIMING LOGIC CIRCUIT

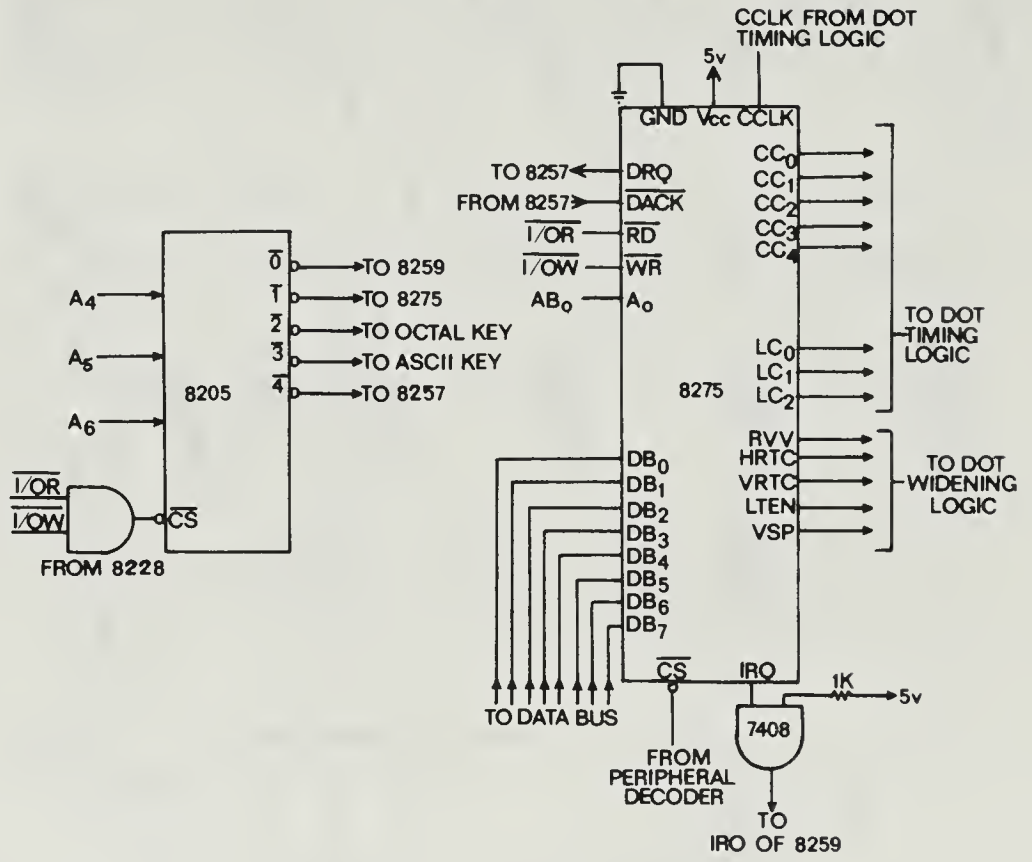

FIG.3 CRT CONTROLLER – PERIPHERAL DECODER DETAILS

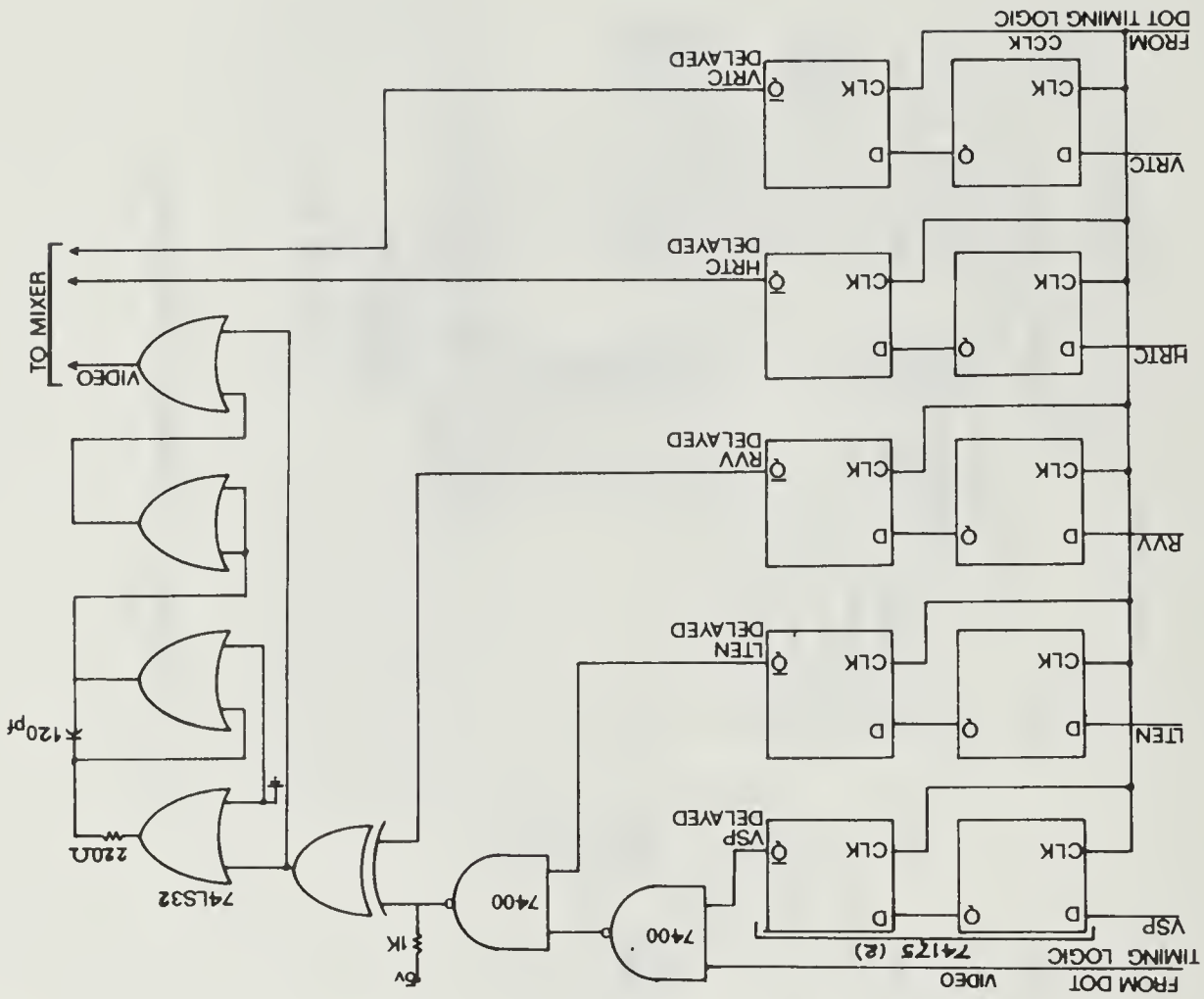

FIG. 5 DOT WIDENING CIRCUIT

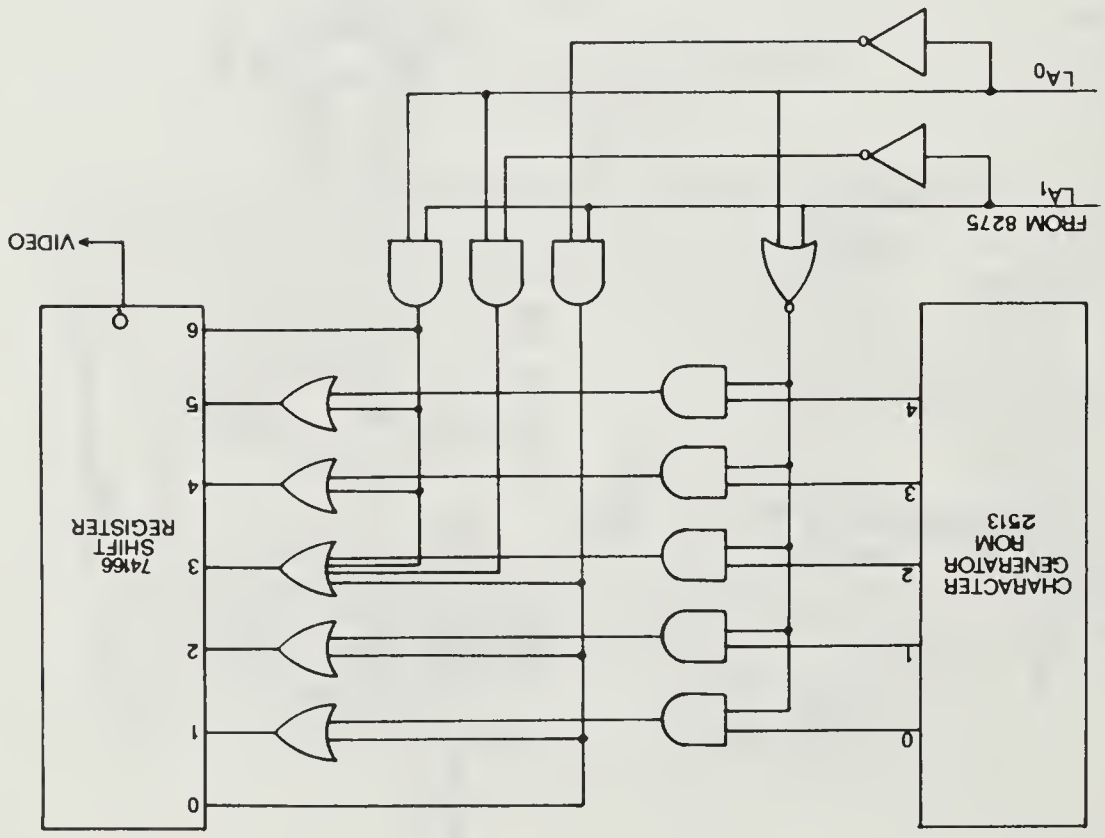

FIG. 6 CHARACTER ATTRIBUTE LOGIC

High 000

Low	Instruction
000	LXI SP
001	000
002	010
003	MVI A; Init. 8259
004	166
005	OUT
006	00H
007	MVI A
010	000
011	OUT
012	01H
013	MVI A; Init. 8275
014	000
015	OUT; Reset
016	X11
017	MVI A; Parameters
020	060
021	OUT
022	10H
023	MVI A
024	127
025	OUT
026	10H
027	MVI A
030	211
031	OUT
032	10H
033	MVI A
034	135
035	OUT
036	10H
037	MVI A; Cursor
040	200
041	OUT
042	11H
043	MVI A; Position X
044	000
045	OUT
046	10H
047	OUT; Position Y
050	10H
051	MVI A; Preset Counters
052	340
053	OUT
054	11H
055	MVI A; Start Oisplay

High 000

Low	Instruction	
056	043	
057	OUT	
060	11H	
061	LXI H; Blank Oisplay Memory	
062	000	
063	010	
064	MVI A	
065	040	
066	MOV M,A	
067	INX H	
070	MOV A,H	
071	CPI	
072	020	
073	JNZ	
074	064	
075	000	
076	LXI H	;Oisplay Memory Pointer
077	000	
100	010	
101	SHLO	
102	200	
103	007	
104	XCHG	
105	LXI H	;Cursor Pointer
106	000	
107	000	
110	SHLO	
111	202	
112	007	
113	EI	
114	HLT	
115	JMP	
116	113	
117	000	
140	JMP; IRO OMA Refresh	
141	000	
142	002	
144	JMP; IR1 Oct. K.B.	
145	067	
146	002	
150	JMP; IR2 ASCII	
151	000	
152	001	

FIG. 8. INITIALIZATION ROUTINE

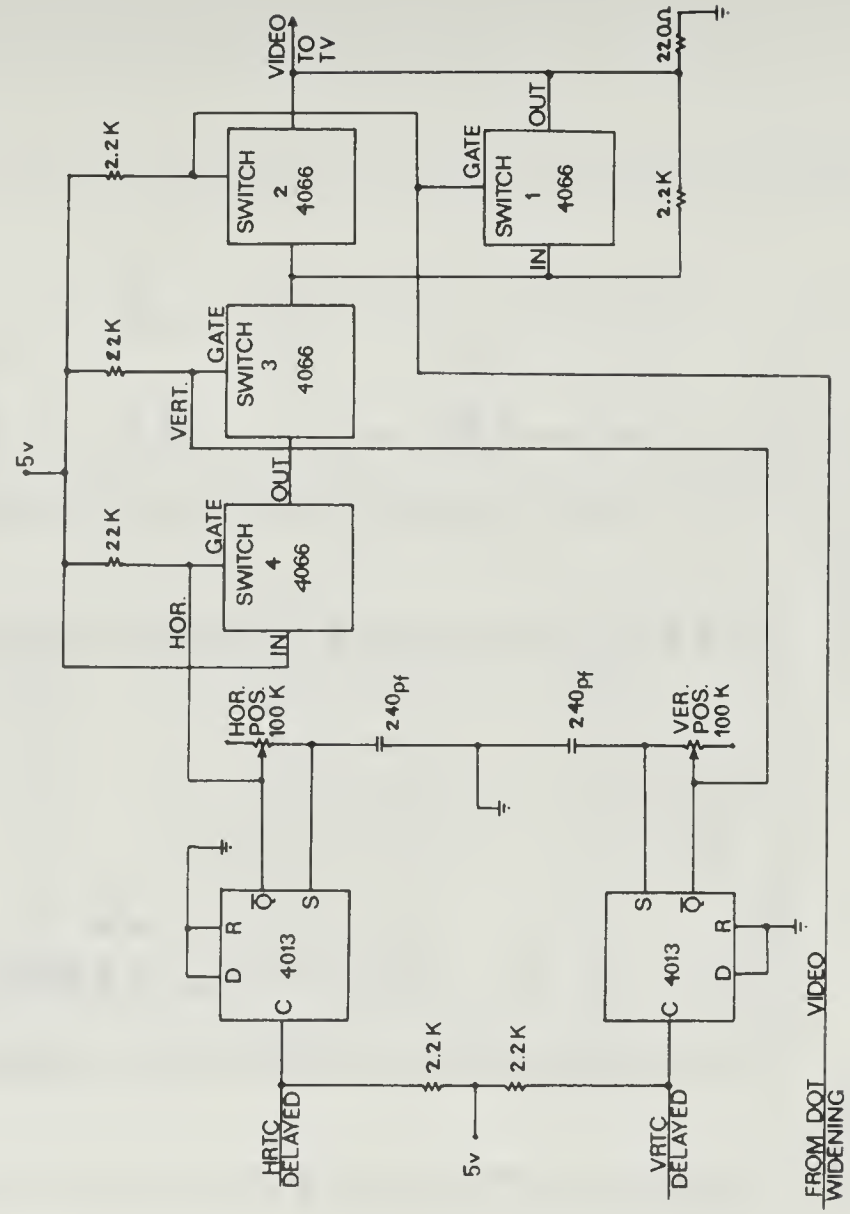

FIG.7 MIXER CIRCUIT WITH CMOS 4066

```
High 002                                    High 002

Low     Instruction                         Low     Instruction
067     373  EI                             145     174  X
070     315  CALL  ;Time Out                146     002  X
071     212  X                              147     376  CPI
072     002  X                              150     010  X    ;S Key
073     333  IN                             151     302  JNZ
074     2XH  X                              152     161  X
075     267  ORA A                          153     002  X
076     362  JP                             154     161  MOV M,C
077     205  X                              155     043  INX H
100     002  X                              156     303  JMP
101     057  CMA                            157     174  X
102     346  ANI                            160     002  X
103     177  X                              161     376  CPI
104     376  CPI                            162     100  X    ;G Key
105     010  X                              163     302  JNZ
106     322  JNC                            164     174  X
107     125  X                              165     002  X
110     002  X                              166     351  PCHL
111     107  MOV B,A                        174     315  CALL    ;Time Out
112     171  MOV A,C                        175     212  X
113     027  RAL                            176     002  X
114     027  RAL                            177     333  IN
115     027  RAL                            200     2XH  X
116     346  ANI                            201     267  ORA A
117     370  X                              202     372  JM
120     260  ORA B                          203     174  X
121     117  MOV C,A                        204     002  X
122     303  JMP                            205     076  MVI A    ;EOI
123     174  X                              206     040  X
124     002  X                              207     323  OUT
125     376  CPI                            210     OOH  X
126     020  X    ;L Key                    211     311  RET
127     302  JNZ                            212     365  PUSH PSW    ;Time Out
130     136  X                              213     325  PUSH D
131     002  X                              214     021  LXI D
132     151  MOV L,C                        215     046  X
133     303  JMP                            216     003  X
134     174  X                              217     033  DCX D
135     002  X                              220     172  MOV A,D
136     376  CPI                            221     263  ORA E
137     040  X    ;H Key                    222     302  JNZ
140     302  JNZ                            223     217  X
141     147  X                              224     002  X
142     002  X                              225     321  POP D
143     141  MOV H,C                        226     361  POP PSW
144     303  JMP                            227     311  RET
```

FIG. 9. OCTAL KEYBOARD SERVICE ROUTINE

```
High 002

Low     Instruction
000     365     PUSH PSW
001     345     PUSH H
002     333     IN          ;Reset 8275 Interrupt
003     11H     X
004     076     MVI A
005     000     X           ;Mode Word Reset
006     323     OUT
007     48H     X           ;Command Register Address
010     052     LHLD        ;Start Scroll, Reserve 000 010(8)
011     200     X
012     007     X
013     175     MOV A,L
014     323     OUT         ;Load Low Order in Channel 2
015     44H     X           ;   for Automatic Load
016     174     MOV A,H
017     323     OUT         ;Load High Order in Channel 2
020     44H     X           ;   for Automatic Load
021     076     MVI A       ;Set Terminal Count High Order for
022     227     X           ;49 X 24 Character Display
023     323     OUT
024     45H     X           ;Terminal Count Low Order
025     076     MVI A
026     204     X
027     323     OUT
030     45H     X           ;Terminal Count High Order
031     076     MVI A       ;Start Address Low Order
032     000     X
033     323     OUT         ;Channel 3 Address
034     46H     X
035     076     MVI A
036     010     X           ;Start Address High Order
037     323     OUT
040     46H     X
041     076     MVI A
042     227     X
043     323     OUT
044     47H     X           ;Terminal Count for Channel 3
045     076     MVI A
046     204     X
047     323     OUT
050     47H     X
051     076     MVI A
052     204     X           ;Set Channel 2 Automatic
053     323     OUT
054     48H     X           ;Mode Set
055     076     MVI A
056     040     X           ;End of Interrupt Command
057     323     OUT         ;Reset 8259
060     00H     X            Interrupt
061     341     POP H
062     361     POP PSW
063     373     EI
064     311     RET
```

FIG. 10. DMA REFRESH ROUTINE

```
High 001

Low
000     EI
001     PUSH H
002     PUSH B
003     MVI B
004     032
005     LXI H   ;Table start
006     214
007     001
010     IN      ;ASCII Input
011     3XH
012     NOP
013     NOP
014     CMP M
015     JNZ
016     036
017     001
020     MOV A,L
021     CPI
022     232
023     JNC
024     031
025     001
026     INX H
027     MOV L,M
030     PCHL
031     INX H
032     MOV A,M
033     JMP
034     046
035     001
036     INX H
037     INX H
040     OCR B
041     JNZ
042     014
043     001
044     ANI
045     077
046     STAX O
047     INX O
050     LHLO
051     202
052     007
053     INR H
054     MOV A,H
055     CPI
056     061
057     JNZ
060     110
061     001
062     MVI H
063     000
064     INR L
065     MOV A,L
066     CPI
067     030
070     JNZ
071     110
072     001
073     PUSH H
074     LHLO
075     200
076     007
077     LXI B
100     061
101     000
102     OAO B
103     SHLO
104     200
105     007
```

```
High 001

Low
106     POP H
107     OCR L
110     MVI A  ;Initiate Cursor
                Command
111     200
112     OUT
113     11H
114     MOV A
115     OUT
116     10H
117     MOV A,L
120     OUT
121     10H
122     SHLO
123     202
124     007
125     POP B  ;End of Interrupt
126     POP H
127     MVI A
130     040
131     OUT
132     00H
133     RET
134     LHLO   ;Back Space
135     202
136     007
137     MOV A,H
140     ORA A
141     JZ
142     146
143     001
144     OCX
145     OCR D
146     JMP
147     110
150     001
151     LXI H   ;Escape-Esc
152     000
153     010
154     SHLO
155     202
156     007
157     XCHG
160     LXI H
161     000
162     000
163     JMP
164     110
165     001
166     LXI H   ;Line Feed
167     061
170     000
171     OAO O
172     XCHG
173     LHLO
174     202
175     007
176     JMP
177     064
200     001
214     BS  210  ;Special Key Table
215     X   134
216     TAB 011
217     X   047
220     LF  012
221     X   166
222     NOP 000
223     NOP 000
224     ESC 033
225     X   151
```

```
High 001

Low
232     A                201   ;Field Attributes
233     X   RVV          220
234     B                202
235     X   BLINK        202
236     C                003
237     X   UNO. LINE    240
240     0                204
241     X   B + C        242
242     E                005
243     X   A + B        222
244     F                006
245     X   A + C        260
246     G                207
247     X   A + B + C    262
250     K                213
251     X   ⌐            300   ;Character Attributes
252     L                014
253     X   ¬            304
254     N                216
255     X   L            310
256     O                017
257     X   ⌋            314
260     Q                021
261     X   ⊤            320
262     R                022
263     X   ⊣            324
264     S                223
265     X   ⊢            330
266     T                024
267     X   ⊥            334
270     U                225
271     X   —            340
272     V                226
273     X   |            344
274     W                027
275     X   +            350
276     OEL              237
277     X                200
```

FIG. 11. ASCII KEYBOARO SERVICE ROUTINE

BAUDOT-MACHINE INTERFACE WITH MICROCOMPUTERS

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This paper describes an interface technique for Baudot machines with microprocessor based computer systems. The hardware for interrupt I/O and software drivers is analyzed in detail.

INTRODUCTION

The exponential growth of microprocessors has stimulated considerable interest in the area of digital peripherals. Modern computer systems can be built with peripherals such as line printers, video terminals, and floppy disk drives. Extensive design changes have been made on the line printers over the past three decades to improve their speed and data handling capabilities. Modern line printers are designed to deal with about 600 wpm in ASCII code whereas the old model, Baudot printers, can operate only at a maximum rate of 100 wpm in Baudot code. These Baudot machines are cheaper and are fast enough for many applications. Programmable I/O ports play an important role in the interface design. These ports are designed to be compatible only with the modern teletypes and therefore, hardware changes and additional circuitry will be needed for implementing Baudot machine-based microcomputer systems. This paper describes an interrupt I/O interface technique for an 8080 based computer system with a Teletype Model 15 KSR Baudot machine.

INTERFACE

The computer system, Fig. 1, consists of a basic system, a teletype model 15 KSR machine, and an USART based-interface circuit. The basic system is implemented with Intel 8080 microprocessor. The system consists of 512 bytes of memory with two pages. The first page of the memory map is implemented with an Intel 1702 UVPROM. The firmware in the UVPROM consists of power up routine, USART initialization routine, teletype keyboard input service driver, and look up table for code conversion. The R/W memory in the second page of the map is for data and user oriented program storage.

The teletype handles data in Baudot code. The keyboard consists of 31 keys representing 57 Baudot characters. The characters are classified into two different categories. All the numeric keys are called 'letters' and the alphabetic and special characters are called 'figures'. The keys can be used in two different modes. If a key is pressed following a 'letter' key, then it is treated as a letter character. A key-press is interpreted as a figure character if it follows a 'figure' key. The Baudot characters are represented by a 5 bit code and a listing of the various Baudot key code assignments is given in Fig. 2. The important aspect of the teletype interface is that the processor deals with parallel data transfer and that the Baudot machine handles the data transfer in serial mode. The keyboard and the printer of the teletype machine can be operated independently with an average speed of 60 wpm. The speed can be increased to a maximum of 100 wpm with a proper drive gear selection. The printer magnet requires a signal with a current capability of at least 60 ma. The USART's incoming data from the teletype must be compatible with TTL-signal requirements. These USART and printer requirements can be achieved by an external power supply and buffering transistors as shown in Fig. 1.

The interface between the teletype and the computer system is by an Intel 8251 USART. The functions of USART are two-fold. It converts the parallel data from the processor into a serial data and the serial data from the Baudot machine into a parallel data. Also, it establishes a hand-shake between the teletype and the processor to compensate for the slow operation of the Baudot machine. The data framing speed of the USART is called Baud Rate and is exclusively controlled by

The frequency of the time, Baud Rate Generator, is determined by the speed of the Baudot machine. For example, for a machine speed of 60 wpm, Table 1, the bit length is 22 ms and the Baud rate is 45 bps ($1/22 \times 10^{-3}$). The Baud rate generator drives both the TXC and RXC of the USART so that the USART transmits and receives the data at the same speed. The timer speed is increased by a factor, Baud Rate Factor, of 16 for efficient data framing. Since the CTS input of the USART is always enabled, whenever the processor fills up the transmit buffer or the TTY transmits data to fill up the receiver buffer, the USART starts data framing synchronously. An interrupt I/O technique is used for transmitting data from the teletype keyboard to the computer system whereas, a software hand-shake technique is used for transmitting data to the printer. The interrupt I/O is achieved by driving the INT input of the processor with RXRDY signal of USART. Whenever a key is pressed, the receiver buffer in the USART will be filled up with the key code. The buffer will then activate the RXRDY signal which in turn interrupts the processor. Upon a qualified INT input, the processor will generate an INTA signal. Since the INTA output of the system is pulled high at 12 volts, the controller places a RST-7 instruction to switch the processor into the keyboard input routine located in trap-7. In the output mode, the processor places an 8 bit data word in the transmit buffer and stays in a loop. In the wait loop, the TXE status of the USART is monitored by the processor. The processor leaves the loop only when the TXE status is detected as active.

SOFTWARE

Upon power up, the system starts with the first page of the memory. The USART is a computerized I/O port. Therefore, it must be programmed before the system is used for data transmission. The initialization routine is located from $000\ 000_8$ to $000\ 025_8$ locations of the UVPROM memory. In this routine, the stack pointer, the register pairs B and D are initialized as a first step. The register pair B is used a pointer for the storage of object program in the R/W memory. The object program is loaded into the system in Baudot octal code through the TTY keyboard. The register paid D is used as a pointer for the storage of the text (Source) in R/W memory in Baudot code. Once the memory pointers are initialized, the mode of the USART is programmed. The mode programming includes framing details such as number of start and stop bits, the data size, and the Baud rate factor. Usually, the number of start bits is chosen to be 1 and stop bits as 2. For Baudot teletype machines, the data size is 5. A Baud rate factor of 16 is chosen for efficient data framing. Data transmission does not start until a command word is programmed into the USART. The command word enables both the transmitter and receiver of the USART. At the end of the initialization, the processor enables the ruption and waits for interruption in halt mode. The flow chart for the power up routine and the initialization program are as in Figs. 3 and 5.

The keyboard input is by interrupt I/O operation. When a key is pressed, the key code is loaded into the receiver buffer os USART. The USART will then switch the processor into the keyboard input routine ($000\ 070_8$ - $000\ 182_8$). In this routine, the processor emptys the USART, stores the data in the text memory using the register pair D, and echos the data back to the printer. The processor waits in a loop reading the status of the USART. As soon as the transmission is complete, the processor starts the object program storage. Before getting into the discussion of the object program storage, it is important to compare and contrast the object program and text. The object program is in object code, 'figures', whereas the text is any Baudot character. The object program is an user-oriented driver, possibly, for the text. Whenever an object program is boot strapped through the keyboard, the keyboard service routine just echos it back as a text and decodes the object program into binary code. In the object program decoding logic, the processor takes three successive octal digits and converts them into an 8 bit binary word using the look-up table ($000\ 030_8$ - 000 047). In order to boot strap a word of an instruction, one has to generate an 8 bit binary word. This binary word can be stored in R/W memory using the register pair B as the pointer and 'S' key as the strobe. The flow chart and a complete listing of keyboard routine are as in Figs. 4 and 7. Once the object program is stored, it can be executed by simply entering the address of the starting location of object program and pressing the 'G' key.

If it is desired to dump the text of any part of the memory, a memory dump program must be boot strapped through the keyboard. When the text is dumped, carriage and line feed options are not needed because these characters are part of the text and are built into the text when it is manually keyed into the memory.

CONCLUSION

The system discussed in this paper is good enough to be a complete terminal if one is not too concerned about the speed. Also, this system does not have any utility program such as assembler. If one wishes to use the Baudot machine as one of the peripherals in the computer system, there must be some provisions for code conversion from Baudot to ASCII code. This can either be done by a look up table or by a character generator. If the peripherals in the system require various clocks, a programmable interval timer such as Intel's 8253 may be used.

REFERENCES

Intel Corporation, *Intel 8080 Microcomputer System User's Manual,* Santa Clara, California, 1977.

Hill-burn J.L., and Julich, P.M., *Microcomputers/Microprocessors: Hardware, Software, and Applications,* Englewood Cliffs, N.J., Prentice Hall, Inc., 1976.

Bruhns, M., *Analysis of Programmable I/O Ports,* Northern Illinois University, DeKalb, Illinois. 1980.

Words Per Minute	Data Rate	Characters Per Second	Bit Pulse Width	Stop Pulse Width	Operations Per Minute
60	45 bps	6	22 ms	31 ms	368
66	50 bps	6.6	20 ms	30 ms	400
75	57 bps	7.5	18 ms	25 ms	460
100	75 bps	10	13.5 ms	19 ms	600

Table 1. Physical Characteristics of Teleprinter Speeds for Baudot Machines

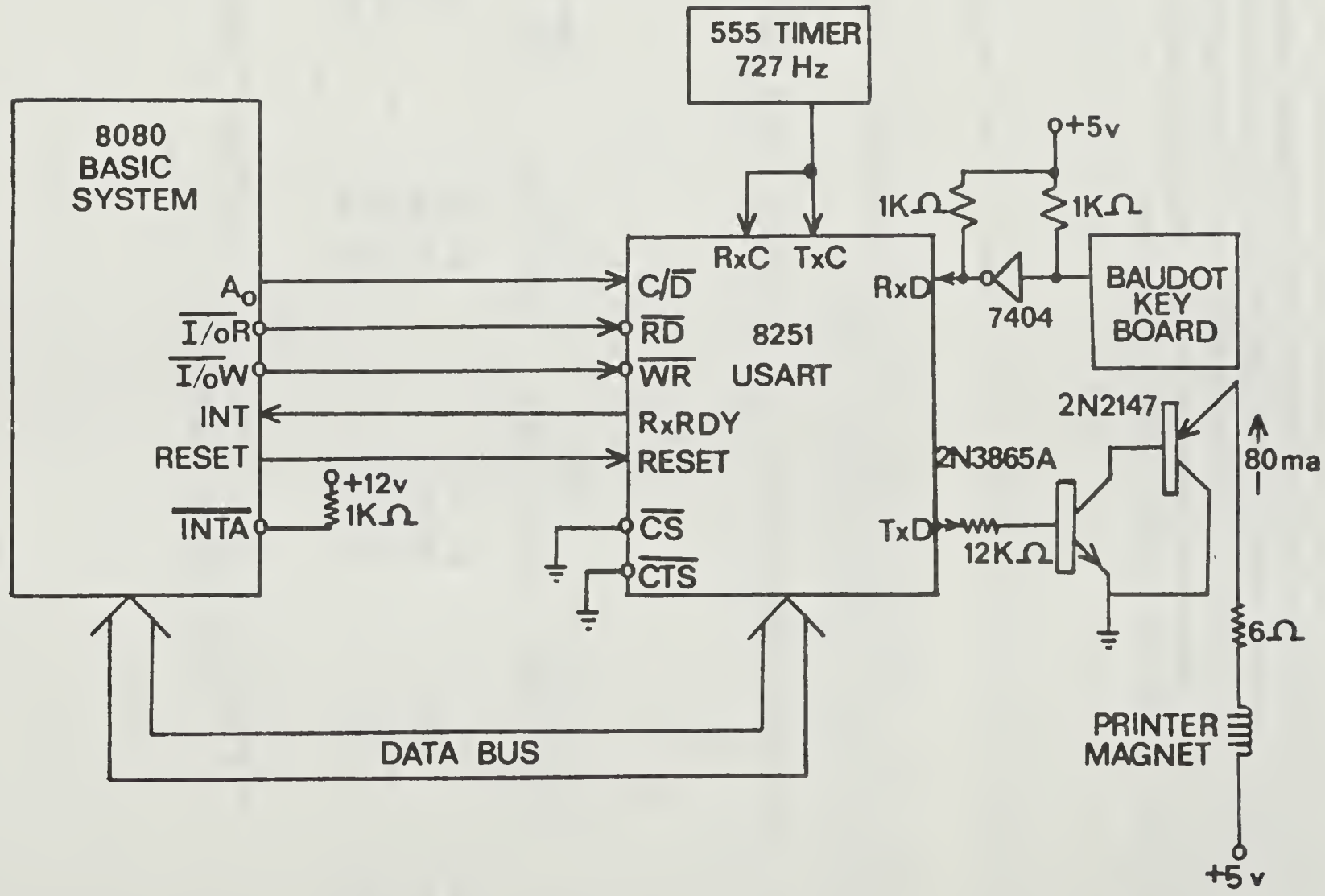

FIG.1 A BAUDOT MACHINE-BASED TERMINAL

	Bit Numbers 5 4 3 2 1	Lower (Letters) Case	Upper (Figures) Case		
			Communications (Standard)	Bell System (TWX) Stock Market	Weather Code
0	0 0 0 0 0	Blank	Blank	Blank	–
1	0 0 0 0 1	E	3	3	3
2	0 0 0 1 0	Line Feed	Line Feed	Line Feed	Line Feed
3	0 0 0 1 1	A	–	–	↑
4	0 0 1 0 0	Space	Space	Space	Space
5	0 0 1 0 1	S	(Apos)	(Apos)	Bell
6	0 0 1 1 0	I	8	8	8
7	0 0 1 1 1	U	7	7	7
8	0 1 0 0 0	Car Ret	Car Ret	Car Ret	Car Ret
9	0 1 0 0 1	D	$ WRU	$	↗
10	0 1 0 1 0	R	4	4	4
11	0 1 0 1 1	J	Bell	Bell	↙
12	0 1 1 0 0	N	,	7/8	○
13	0 1 1 0 1	F	!	1/4	→
14	0 1 1 1 0	C	:	1/8	•
15	0 1 1 1 1	K	(	1/2	←
16	1 0 0 0 0	T	5	5	5
17	1 0 0 0 1	Z	+	"	+
18	1 0 0 1 0	L	)	3/4	↖
19	1 0 0 1 1	W	2	2	2
20	1 0 1 0 0	H	#	#	↓
21	1 0 1 0 1	Y	6	6	6
22	1 0 1 1 0	P	0	0	0
23	1 0 1 1 1	Q	1	1	1
24	1 1 0 0 0	O	9	9	9
25	1 1 0 0 1	B	?	5/8	•
26	1 1 0 1 0	G	&	&	↘
27	1 1 0 1 1	Figures	Figures	Figures	Figures
28	1 1 1 0 0	M	.	.	.
29	1 1 1 0 1	X	/	/	/
30	1 1 1 1 0	V	=	3/8	•
31	1 1 1 1 1	Letters	Letters	Letters	Letters

Figure 2. Baudot key code Assignment

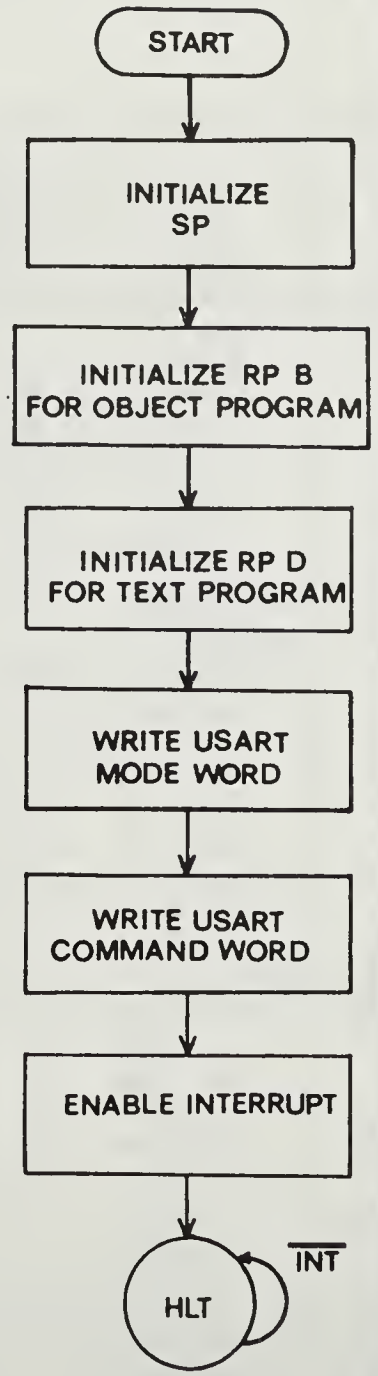

FIG.3 INITIALIZATION

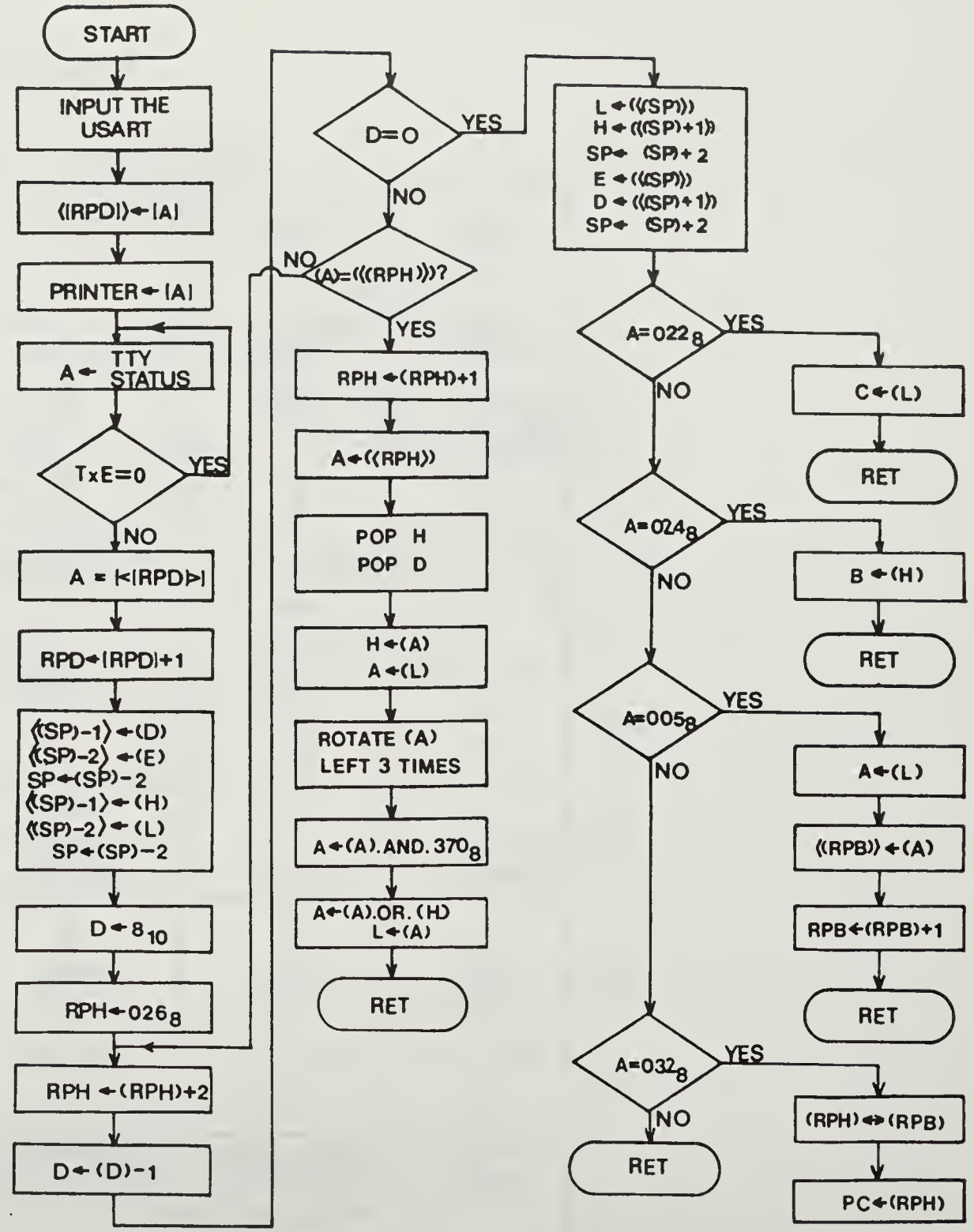

FIG. 4 FLOW CHART FOR TTY INPUT

```
    Instruction
000 LXI SP          Initialize the stack pointer
001 000
002 002
003 LXI B           Initialize the object memory
004 000             pointer
005 001
006 LXI D           Initialize the text memory pointer
007 200
010 001
011 MVI A           Set USART mode
012 302
013 OUT
014 001
015 MVI A           Enable the transmitter and
016 047             receiver
017 OUT
020 001
021 EI              Enable Interruption
022 HLT
023 JMP
024 021
025 000
```

FIGURE 5. Initialization Program

```
030 001             Baudot 3
031 003
032 007             Baudot 7
033 007
034 012             Baudot 4
035 004
036 020             Baudot 5
037 005
040 025             Baudot 6
041 006
042 026             Baudot 0
043 000
044 027             Baudot 1
045 023
046 023             Baudot 2
047 002
```

FIGURE 6. Baudot to Binary look-up table

```
    Instruction
070 IN              Input the USART
071 000
072 STAX D          Store in memory
073 OUT             Echo it on TTY
074 000
075 IN              Read USART
076 001             Status
077 ANI
100 004
101 JNZ             Stay in the
102 075             loop until TXE=1
103 000
104 LDAX D          Retrieve the data
105 INX D           Increment pointer
106 PUSH D          Save the pointer
107 PUSH H
110 MVI D           Set the table size
111 010
112 LXI H
113 026
114 000
115 INX H
116 INX H
117 DCR D
120 JZ              Jump if 'letter'
121 145
122 000
123 CMP M           Move binary code
124 JNZ
125 115
126 000
127 INX H
130 MOV A, M
131 POP H
132 POP D
133 MOV H,A
134 MOV A,L
135 RAL
136 RAL
```

```
    Instruction
137 RAL
140 ANI
141 370
142 ORA H
143 MOV L,A
144 RET
145 POP H
146 POP D
147 CPI             Check if 'L' key
150 022
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163 MOV B, H
164 RET
165 CPI             Check if 'S' key
166 005
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175 RET
176 CPI             Check if 'G' key
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200 RNZ
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FIGURE 7. TTY Keyboard input routine

MEGAFOSSIL ZONATION OF THE LINGLE AND ST. LAURENT LIMESTONES (MIDDLE DEVONIAN) OF SOUTHERN ILLINOIS AND SOUTHEASTERN MISSOURI

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ABSTRACT

Four invertebrate magafossil zones, the *Microcyclus* zone, the *Devonochonetes/Actinopteria/Phthonia* zone, the *Favosites* zone, and the *Spinocyrtia* zone, in ascending order, have been identified in the upper Middle Devonian Lingle and St. Laurent Limestones in southern Illinois and southeastern Missouri. In addition, one bed, the *Syringostroma/Anostylostroma* bed, has been identified in the middle part of the St. Laurent Limestone in Quarry Hill. This bed correlates with the middle part of the *Devonochonetes/Actinopteria/Phthonia* zone. The zonation presented here indicates that the Lingle and St. Laurent Limestones are stratigraphically equivalent.

INTRODUCTION

For some time there has been uncertainty regarding the stratigraphic relationships between the upper Middle Devonian Lingle Limestone in southern Illinois and the St. Laurent Limestone in southeastern Missouri. Croneis (1944) pointed out that because of the discontinuity of the Devonian outcrops in the area of the Ste. Genevieve Fault System, the complexly faulted condition of most of these rocks, and their partial nonexposure in many areas accurate correlation is difficult. As J.M. Weller (1944) noted, the correlations of this part of the section in the southern Illinois area have been long range due to the uneven distribution of the faunas and the lack of detailed knowledge of the Lingle faunas. The same might have been said for the St. Laurent faunas. He also stated that correlations based solely on lithologic and stratigraphic seccession had not proven successful in unraveling the problem and suggested a comprehensive faunal study and review of correlations for the upper Middle Devonian rocks in southern Illinois. Cooper (1944) observed that the faunas of the Lingle were not necessarily present in the St. Laurent making correlation of the two units difficult, and that there was a problem in attempting to correlate within the St. Laurent when going from the southern Perry County area into the northern Perry County and southern Ste. Genevieve County area in southeastern Missouri (See FIG. 1).

These latter correlation problems are addressed by this study.

A map showing the collecting localities is included as FIGURE 1, while sections showing the distribution of the megafossil zones appears as FIGURE 2, illustrations of index and characteristic fossils are in FIGURE 3, and a Devonian correlation chart is included as FIGURE 4.

PREVIOUS WORK

In 1868 Meek and Worthen described and figured a number of species from the Middle Devonian of southern Illinois (Lingle), and Worthen (1868) published his reports on the Geology of Union and Jackson Counties in southern Illinois. Likewise, in 1894, C.R. Keys described and figured several species from the Middle Devonian of southeastern Missouri (St. Laurent). Stuart Weller (1897) listed the fossils he had collected and identified from the north face of the Bakeoven at Grand Tower and zoned the Middle Devonian rocks there. T.E. Savage (1907,1908) discussed the stratigraphy of the lower Paleozoic rocks, including those of the Middle Devonian, from southwestern Illinois. Dake (1918)applied the name St. Lorenz to the Devonian beds lying between the Beauvais Sandstone and the Chattanooga Shale in southeastern Missouri.

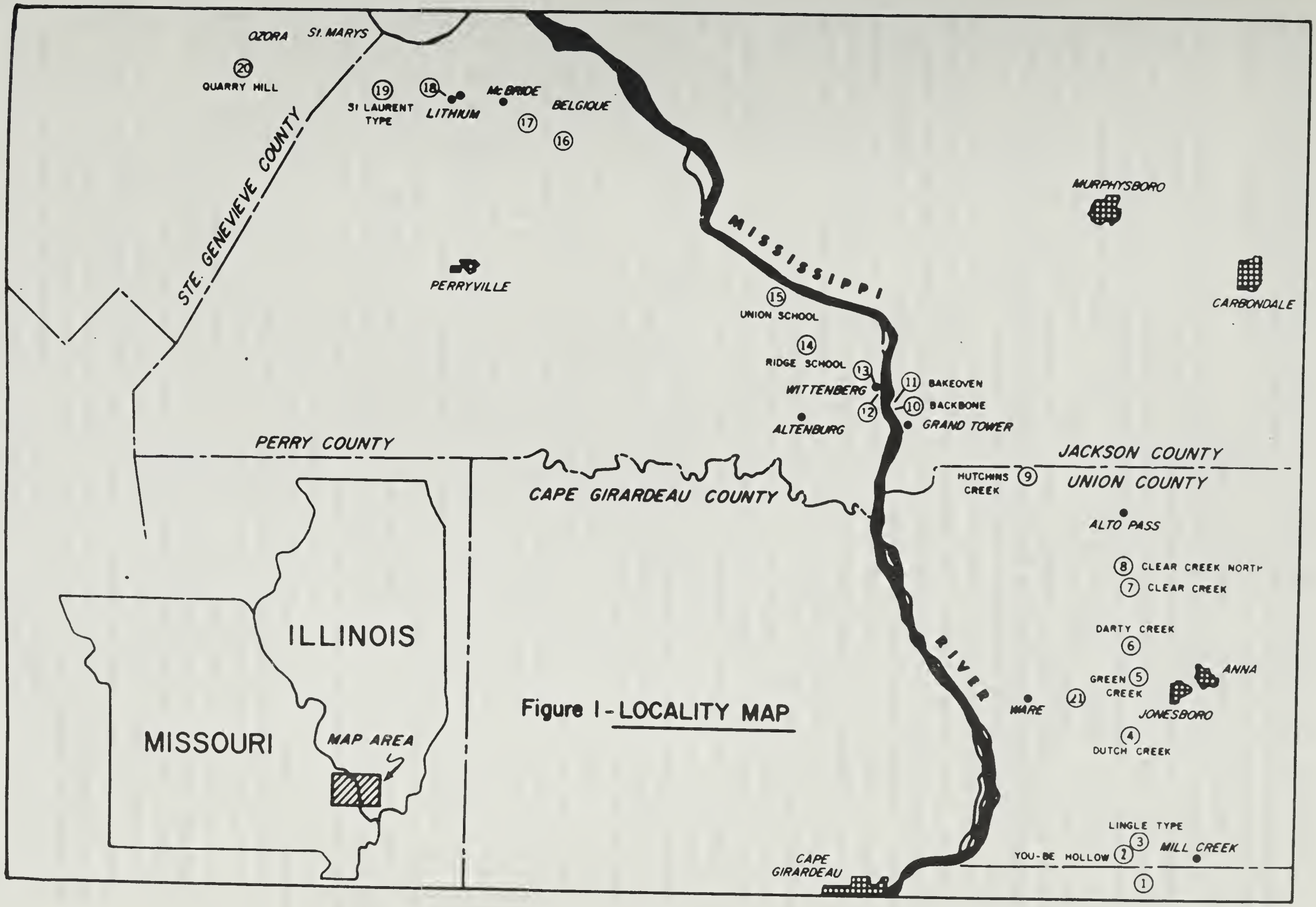


Figure 1 - LOCALITY MAP

In 1920, Savage described the Devonian formations of southern Illinois and named the Misenheimer and Lingle formations. Wilson (1922) changed the name applied to the Devonian beds above the Beauvais Sandstone from St. Lorenz to St. Laurent following Stuart Weller, unpublished report of the Missouri Bureau of Geology and Mines.

E.B.Branson (1922) published the ''Devonian of Missouri'' in which he described the Devonian formations of southeastern Missouri and listed the fossils that had been identified from each formation. In 1923, C.F. Bassett described the Devonian formations in the Alto Pass Quadrangle of Union County in southern Illinois, and T.E. Savage (1925)compared the Devonian rocks of Illinois with those in Missouri. Also in 1925, R.F. Flint mapped the Devonian rocks in Perry County in southeastern Missouri and listed the megafauna of each formation. Weller and St. Clair (1928) published a map of the geology of Ste. Genevieve County in southeastern Missouri, described the Devonian formations in the area, and noted the fossils found in each. In 1942, Cooper and Warthin discussed new Devonian (Hamilton) correlations involving the southern Illinois-southeastern Missouri area. Cooper, et. al., (1942), published an up to date correlation chart for the Devonian in North America which indicated the stratigraphic relationships of local Devonian rocks to those of adjacent areas. E.B. Branson (1944) published the ''Geology of Missouri'' in which he discussed the lithology, fauna, and relationships of the Devonian formations in Missouri. Also in that year, G.A. Cooper (1944) discussed the correlation of Devonian formations in Illinois and adjacent states in the Symposium on Devonian Stratigraphy. In this latter publication, Carey Croneis reviewed the Devonian of southeastern Missouri, and J.M. Weller reviewed the Devonian System in southern Illinois and discussed correlations. G.A. Cooper (1944) described the *Microcyclus* zone of the St. Laurent, while Stumm (1949) and Stauffer (1952) named new species and discussed other occurrences of *Microcyclus.* In 1965 Satterfield mapped the bedrock of the Cobden Quadrangle in Union County in southern Illinois, measured the most representative section of the Lingle and the type section of the Alto Formation on Clear Creek, and published a guidebook on the Devonian of Jackson and Union Counties in southern Illinois. Also in that year, Meents and Swann published their circular on the Grand Tower Formation in which they noted the distribution of the Lingle Limestone. In 1966, J.F. Baesemann completed his study of the spiriferid brachiopods from the Lingle and J.A. Norton completed his study of the petrology of the Lingle Limestone. Also in 1966, J.C. Grimmer finished his study of the invertebrate megafossils and stratigraphy of the Middle Devonian shales of southern Illinois. He published the results two years later (1968). Collinson (1967) and Collinson and others (1967) in the Symposium on the Devonian System discussed the Devonian in the North Central Region of the U.S. and published a correlation chart on the Devonian. Also in 1967 Fraunfelter discussed the correlation of the Lingle and St. Laurent Limestones in southern Illinois and southeastern Missouri. In 1968 Roger Nance completed his study of the petrology of the St. Laurent Limestone in southeastern Missouri. The following year J.C. Engstrom (1969) finished his study of the invertebrate magafauna of the *Microcyclus* zone of the St. Laurent Limestone in southern Illinois and southeastern Missouri and W.G. North published his report on the Devonian strata of southern Illinois in which he divided the Lingle into four members and one bed, described those units, and showed their surface and subsurface extent. In 1970, Fraunfelter and Engstrom published a study on *Microcyclus* which concluded that *M. discus* Meek & Worthen was the only valid species of that genus. From 1970 to 1977 Fraunfelter, Baesemann (1972) and Birkhead (1973) published reports on the paleontology of the Lingle and St. Laurent Limestones. In 1978 and 1979 Fraunfelter discussed the invertebrate megafossil zonation of the Lingle and St. Laurent Limestones. Fraunfelter (1973, and 1977) published on the Middle Devonian Limestones of southern Illinois and their stratigraphy.

Detailed studies of the invertebrate megafauna from the upper Middle Devonian Lingle and St. Laurent Limestones in southern Illinois and southeastern Missouri have revealed the presence of four megafossil zones and one bed. The oldest of these zones is the *Microcyclus* zone which was recognized by Cooper, *et al.,* (1942) at the Union School and Bakeoven localities (See FIGS. 1 and 2). This zone can be recognized by the presence of the index fossil *Microcyclus discus* Meek & Worthen (See FIG. 3). The presence of *Aulacophyllum multiseptum* Fraunfelter, *Tylothyris? bella* Cooper, *Leptaena trilobamuscula* Fraunfelter & Baesemann, and *Phacops rana crassituberculata* Stumm is also characteristic. Overlying the *Microcyclus* zone is the

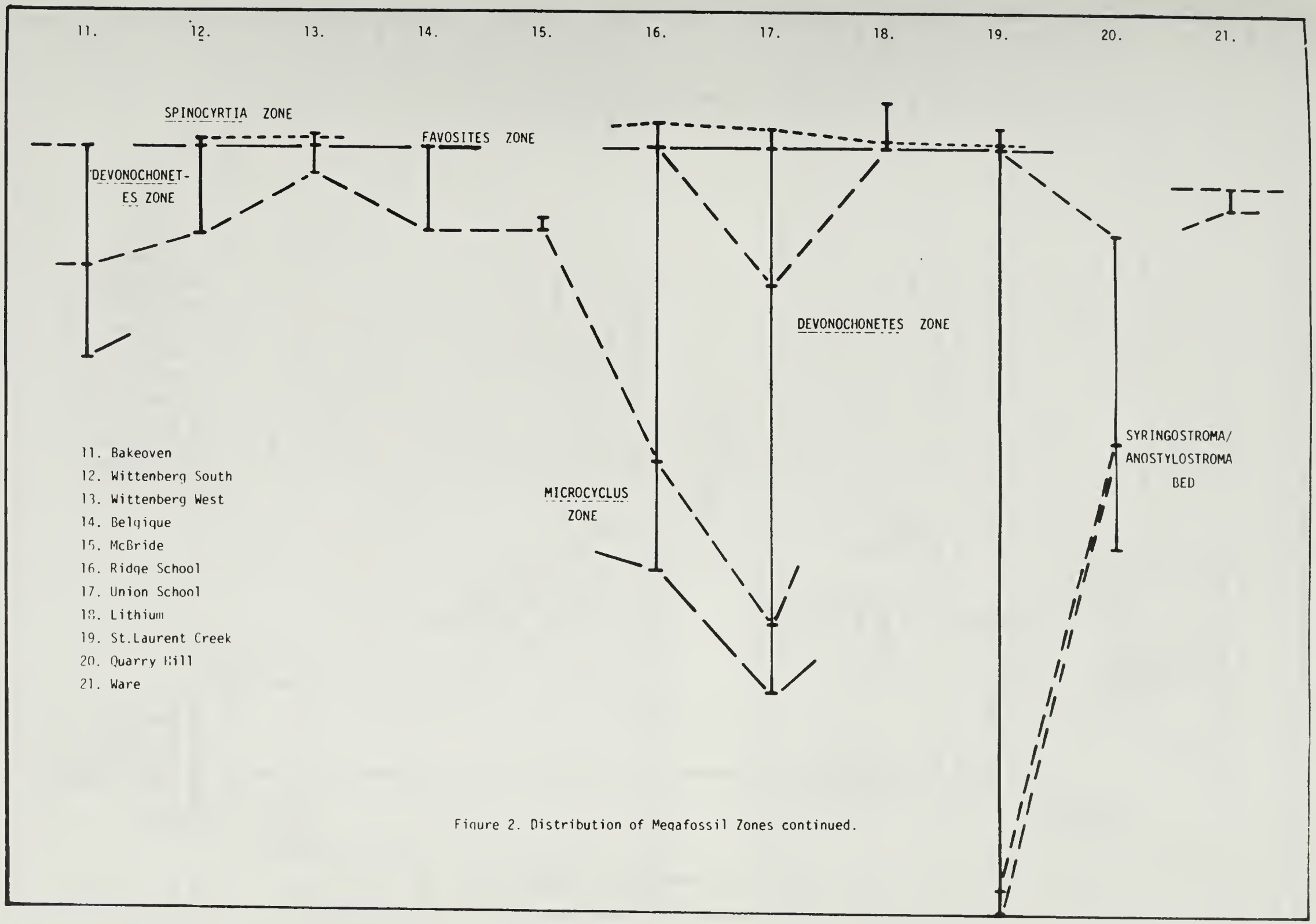
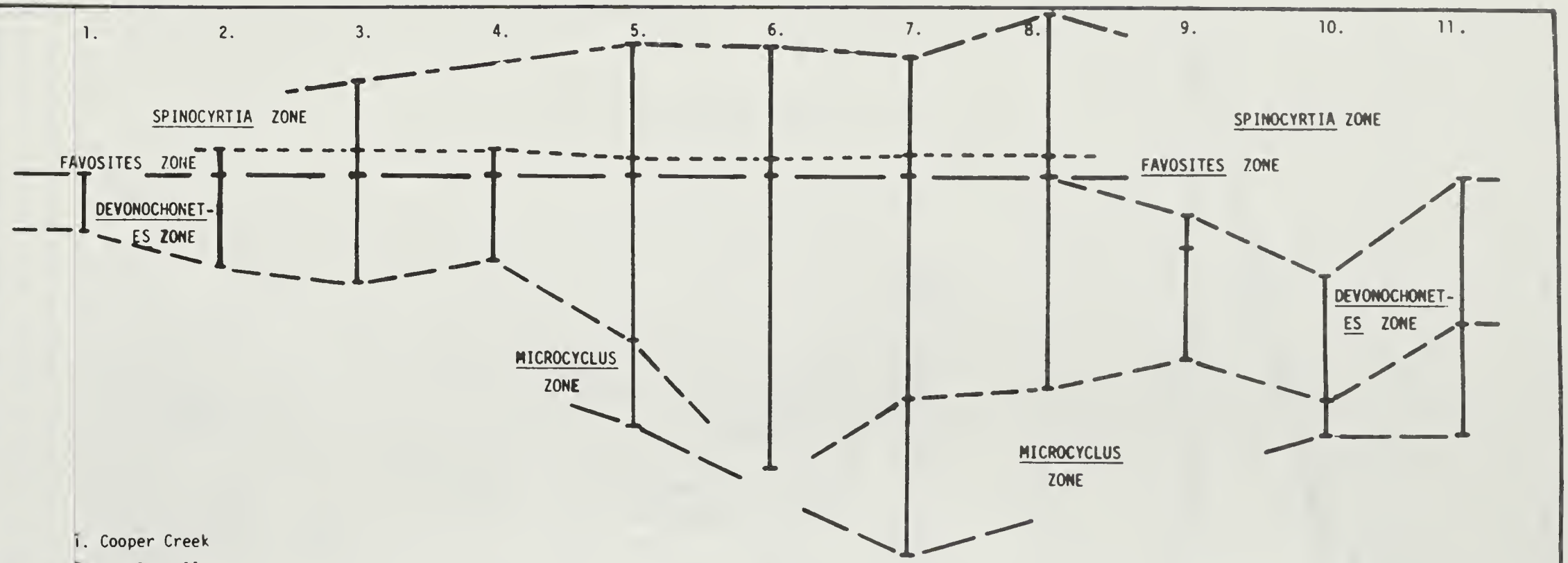


Figure 2. Distribution of Megafossil Zones continued.



1. Cooper Creek
2. You-Be Hollow
3. Lingle Type
4. Dutch Creek
5. Green Creek
6. Darty Creek
7. Clear Creek
8. Clear Creek North
9. Hutchins Creek
10. Backbone
11. Bakeoven

Figure 2. Distribution of Megafossil Zones

Devonochonetes/Actinopteria/Phthonia zone which contains the index fossil *Devonochonetes gibberus* Fraunfelter & Baesemann in the limestone facies of this zone and *Actinopteria muricata* (Hall) and *Phthonia* sp., cf. *P. cylindrica* in the siltstone/shale facies. The limestone facies also characteristically contains *Devonochonetes amplus* (Cooper), *Spinulicosta spinulicosta* (Hall), *Cupularostrum? prolifica* (Hall), and *Tabulophyllum callawayensis* (Branson), while the siltstone/shale facies characteristically contains *Productella* sp. and *Camarotoechia* sp. along with *Aviculopecten* sp., cf. *A. fasciculatus* Hall, *Aviculopecten* sp., cf. *A. bellus* (Conrad) and *Paleoneilo* sp., cf. *P. maxima* (Conrad). Cooper in 1942 noted the presence of large numbers of *Tropidoleptus* and *Chonetes* cf. *coronatus* in this part of the Lingle in southern Illinois. The *Favosities* zone occurs above the *Devonochonetes/Actinopteria/Phthonia* zone. It is recognized by the presence of the colonial coral *Favosites alpenensis* Winchell. It is also characterized by the presence of *Eridophyllum archiaci* (Billings), *Pleurodictyum* sp., cf. *P. wardi* Greene, *Pustulatia pustulatia* (Hall), *Centronella impressa* Hall, *Delthyris sculptilis* Hall, *Megistocrinus* sp., cf. *M. depressus* Hall, and *Megistocrinus* sp., cf. *M. pernodosus* Thomas. Cooper (1942) called this zone the *Vitulina (Pustulatia)* zone and noted its presence in the Lingle type section on Lingle Creek in southern Illinois. The youngest of the zones recognized, the *Spinocyrtia* zone, contains the index fossils *Spinocyrtia ravenswoodensis* Ehlers & Wright and *Spinocyrtia granulosus* (Conrad), and characteristically also contains *Heteroschisma* sp. and *Nortonechinus* sp. The one bed recognized, the *Syringostroma/Anostylostroma* bed, contains the index fossils *Syringostroma superdensum* Galloway & St. Jean and *Anstylostroma* sp., cf. *A. confluens* Galloway & St. Jean. Characteristically, *Favosites* sp., cf. *F. clausus* Rominger, *Emmonsia* sp., cf. *E. digitatus* Rominger, and *Favosites alpenensis* Whinchell var. also occur in this bed.

DISCUSSION

In 1944 Croneis correlated the St. Laurent with the Hamilton of the New York and Ohio valley sections, while J.M. Weller (1944) correlated the St. Laurent with the Lingle (See FIG. 4). Cooper (1942 & 1944) correlated his *Vitulina (Pustulatia)* zone in the middle part of the Lingle at the Lingle type section with the Beechwood Limestone of southern Indiana and northern Kentucky. The *Microcyclus* zone, which Cooper placed at the base of the St. Laurent, was recognized at the Union School section in southeastern Missouri, and at the Bakeoven and on Clear Creek in southern Illinois. In the interval between these two zones Cooper noted the abundant occurrence of *Tropidoleptus* and *Chonetes* cf. *C. coronatus* in the Bakeoven at Grand Tower in southern Illinois. The *Microcyclus* zone occurs at the base of the St. Laurent in the Green Creek, Clear Creek, Backbone, Bakeoven, Ridge School, and Union School sections (See FIG. 2) Hence. *Microcyclus* is abundant in the most complete section of the Lingle on Clear Creek in southern Illinois. The *Devonochonetes/Actinopteria/Phthonia* zone, ie., the siltstone/shale facies, can be recognized as far south as Cooper Creek in northern Alexander County in southern Illinois, and as far north as Ridge School in southern Perry County, Missouri. The equivalent part of the section is not exposed at Union School (See FIG. 2). The limestone facies of this zone extends from Green Creek in southern Illinois to St. Laurent Creek in northern Perry County, Missouri. In Quarry Hill in southern Ste. Genevieve County, the limestone is replaced by sandstone, but the zonal megafossils remain. The *Vitulina (Pustulatia)* zone of Cooper is more easily recognized in the field by using the colonial corals it contains, hence the use of the name *Favosites* zone. Cooper's suggestion that the uppermost bed at Union School might be *Vitulina (Pustulatia)* zone equivalent is correct. *Pustulatia pustulosa, Centronella impressa,* and *Delthyris sculptilis* are all found in these beds along with *Pleurodictyum* sp., cf. *P. wardi*. This zone *(Favosites)* occurs not only in the Lingle type section as recognized by Cooper, but also on Green Creek, Darty Greek, Clear Creek, Clear Creek North, Wittenberg South, Wittenberg West, Ridge School (?), Union School, and on St. Laurent Creek (See FIG. 2). The *Spinocyrtia* zone can be traced from the Lingle type section northwestward to the Wittenberg South section just across the Mississippi River from Grand Tower. Northwestward of the latter section the upper part of the Lingle/St. Laurent is not exposed or does not contain *Spinocyrtia* or other characteristic fossils.

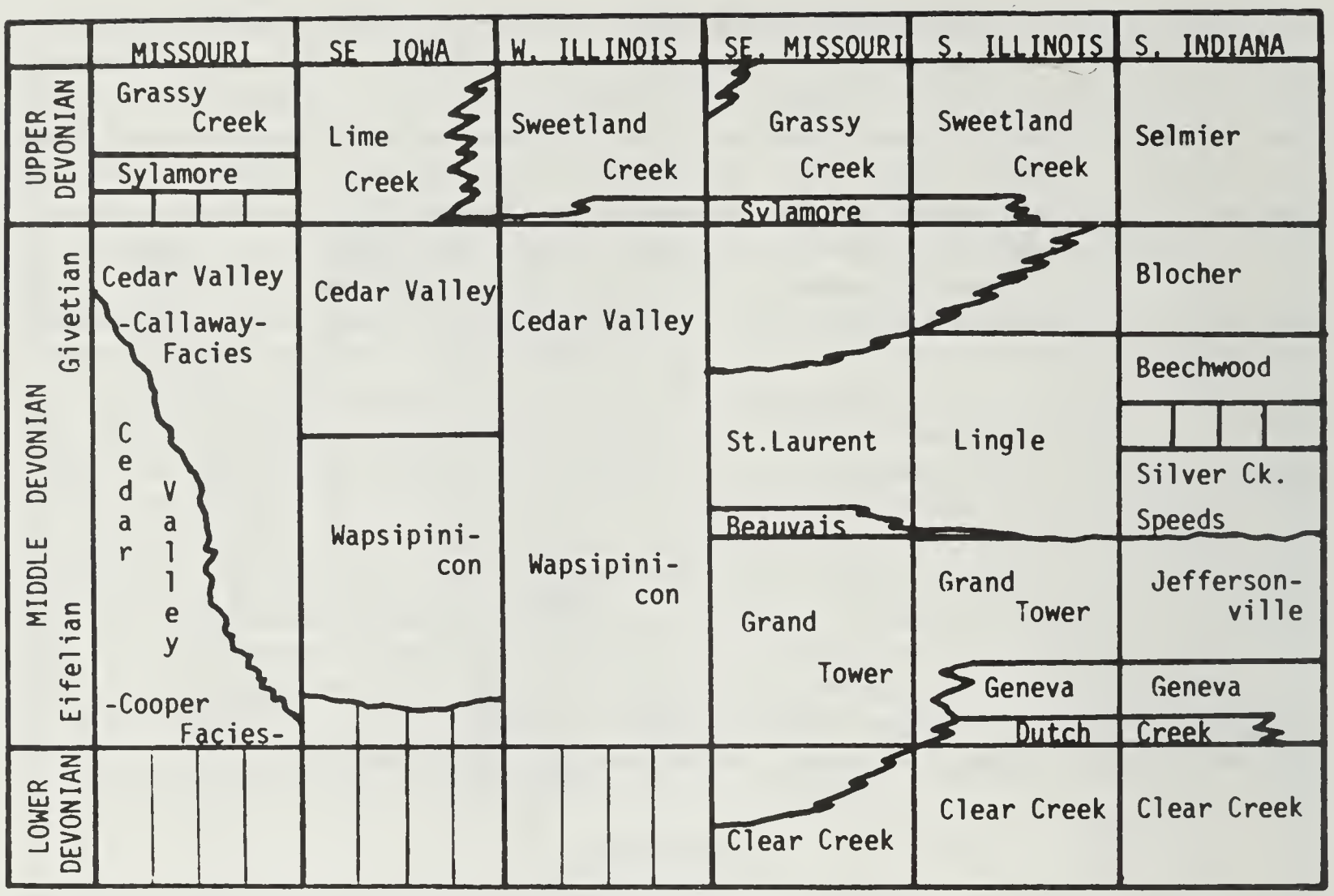


Figure 4. Devonian Correlation Chart

On St. Laurent Creek, the type section of the St. Laurent Limestone, only six feet of section lie above the thin (eight to ten inches) *Favosites* zone, and the *Favosites* zone if it was ever present in the Quarry Hill Section has since been eroded (See FIG. 2). Thus, the upper part of the section is well-developed in southern Illinois and in southern Perry County, Missouri, but not in northern Perry County and southern Ste. Genevieve County, Missouri. The *Microcyclus* zone does not occur in the sections south of Green Creek in southern Illinois, is well-developed from Green Creek to Union School, but none of the limestones near the base of the sections on St. Laurent Creek and in Quarry Hill contain *Microcyclus*. In these latter two sections the lower limestones interfinger with the Beauvais (See FIG. 2).

CONCLUSIONS

1. The invertebrate megafossil zones recognized in the Lingle Limestone can be traced into the St. Laurent Limestone.
2. The Lingle and St. Laurent Limestones are stratigraphically equivalent, so that there is no need to refer the lower part of the upper Middle Devonian of the area to the St. Laurent and the middle and upper parts of the sequence to the Lingle.
3. The oldest zone, the *Microcyclus* zone, is not developed in the southern outcrop areas in southern Illinois, but is well developed in the central and northern parts of the outcrop area under consideration. On the other hand. the *Spinocyrtia* zone, the youngest zone, is well developed in southern Illinois but not in southeastern Missouri, except near Wittenberg. Hence, it appears that the oldest St. Laurent is older than the oldest Lingle, and the youngest Lingle, is younger than the youngest St. Laurent as suggested by J.M. Weller (1944).

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Figure 3A

1. Microcyclus discus (X 1) calical view
2. Tylothyris? bella (X 2) brachial view
3. Aulacophyllum multiseptum (X 1) calical view
4. Leptaena trilobamuscula (X 1) pedicle view
5. Phacops rana crassituberculata (X 1.25) dorsal view
6. Devonochonetes gibberus (X 1) pedicle view
7. Actinopteria muricata (X 2) left view
8. Phthonia cf. P. cylindrica (X 1.5) top view
9. Devonochonetes amplus (X 1.25) pedicle view
10. Spinulicosta spinulicosta (X 2) pedicle view
11. Cupularostrum? prolifica (X 2.5) pedicle view
12. Tabulophyllum callawayensis (X 1.5) longitudinal section
13. Tabulophyllum callawayensis (X 1.25) cross section
14. Productella sp. (X 1.5) pedicle and brachial views
15. Camarotoechia sp. (X 1.5) pedicle view
16. Aviculopecten cf. A. fasciculatus (X 2) lateral view (left)
17. Aviculopecten cf. A. bellus (X 2) lateral view (left)
18. Paleoneilo cf. P. maxima (X 1.25) lateral view (left)
19. Tropidoleptus carinatus (X 1.25) pedicle view

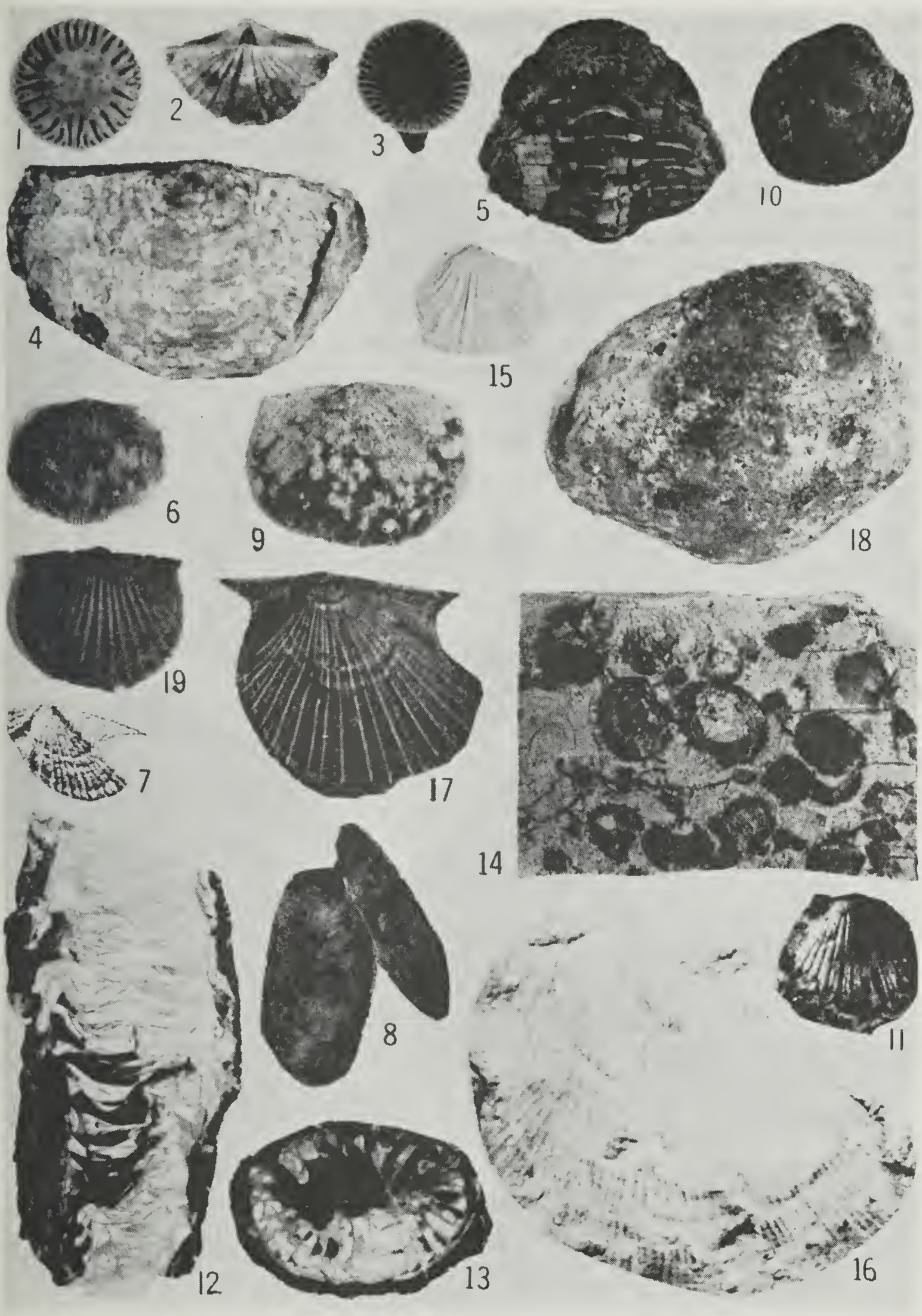
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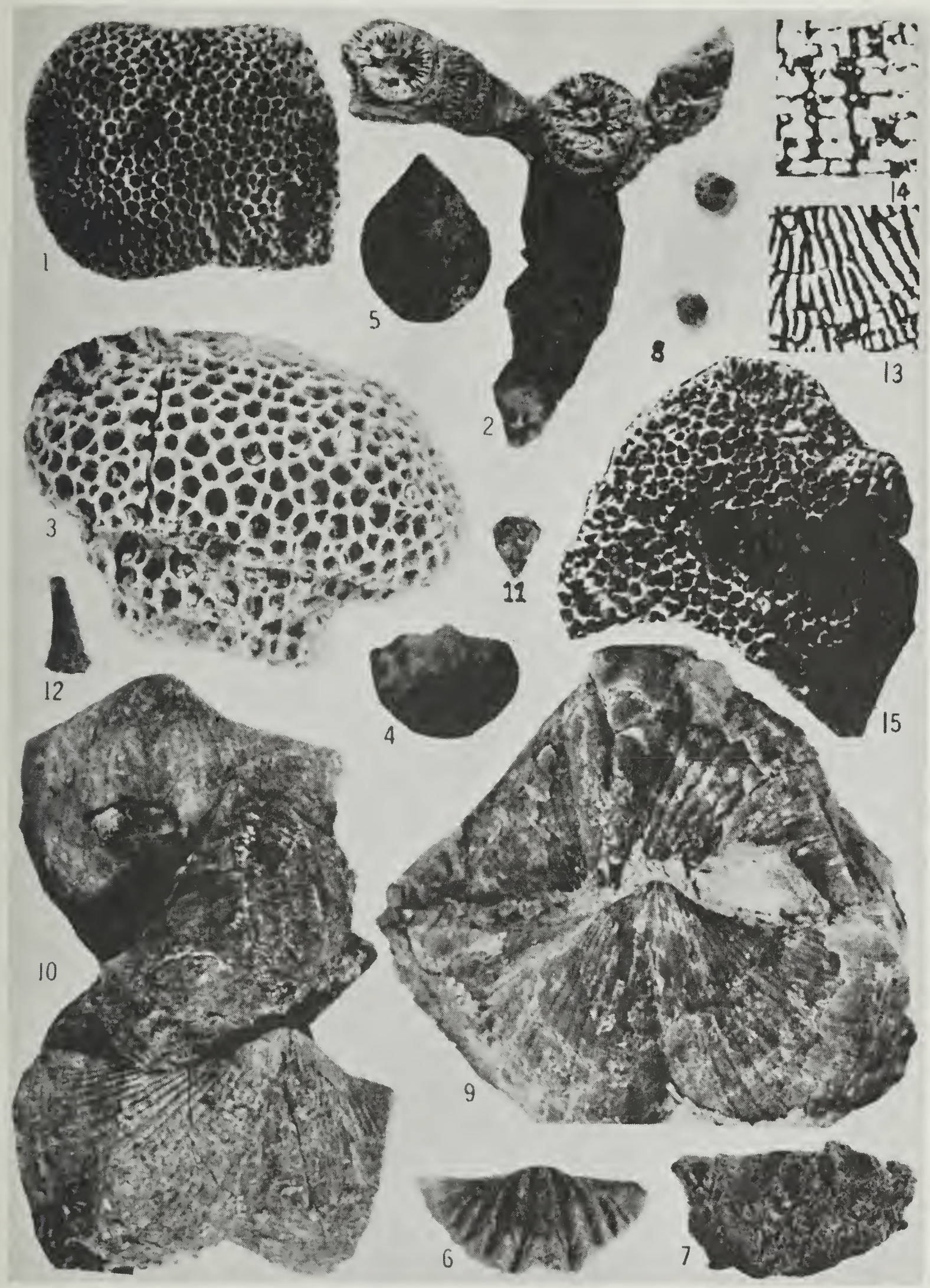
Figure 3B

1. Favosites alpenensis alpenensis (X 1.25) calical view
2. Eridophyllum archiaci (X 1.5) calical view
3. Pleurodictyum cf. P. wardi (X 1) lateral view
4. Pustulatia pustulatia (X 2.5) pedicle view
5. Centronella impressa (X 2) pedicle view
6. Delthyris sculptilis (X 1.5) brachial view
7. Megistocrinus cf. M. depressus (X 1.25) lateral view
8. Megistocrinus cf. M. pernodosus (X 2) top view of plates
9. Spinocyrtia ravenswoodensis (X 2) top view
10. Spinocyrtia granulosus (X 1.5) pedicle view
11. Heteroschisma sp. (X 2) lateral view
12. Nortonechinus sp. (X 3) lateral view of spine
13. Syringostroma cf. S. superdensum (X 10) cross section
14. Anostylostroma cf. A. confluens (X 10) cross section
15. Emmonsia cf. E. digitatus (X 2) lateral view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ERRATUM

Numbers of 3 and 4 of Volume 72 mistakenly carry the date of 1980. They should instead read 1979.

NOTICE

Dr. Basil C. Hedrick has resigned as editor of the Transactions of the Illinois State Academy of Science effective with the final publication of Volume 73 (1980). Beginning with Volume 74 (1981) the editorship will be shared by Dr. Anthony Paparo and Dr. L. Richard Coulson, Southern Illinois University School of Medicine, Southern Illinois University at Carbondale, Carbondale, Illinois 62901. Please address all manuscripts and editorial correspondence to their attention.

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A SUMMARY OF THE ANIMAL REMAINS FROM THE NOBLE-WIETING SITE (IIML28), MCLEAN COUNTY, ILLINOIS

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ABSTRACT

Identifications and analysis of approximately 8100 vertebrate remains and 110 freshwater mussel valves recovered at the Noble-Wieting Site (11ML28), McLean County, Illinois are presented. A minimum of 53 vertebrate species and 302 individuals were represented in the sample. Occupants of this prehistoric Upper Mississippian village utilized a large variety of endemic animals, but the white-tailed deer and elk comprised the major meat resources in the food economy of these people.

INTRODUCTION

Periodically during the years 1966 and 1968-1970 Mr. Fred B. Brian, formerly with the School of Art, Illinois Wesleyan University, Bloomington, and students excavated a portion of a Late Woodland-Early Mississippian village known as the Noble-Wieting Site (11ML28). This site is located approximately one mile (1.6 km) north of Heyworth and one-third mile (.5km) west of the confluens of Little Kickapoo Creek with Kickapoo Creek, McLean County. A total of approximately 2600 bone pieces and 51 freshwater mussel valves were recovered from a shallow fire pit (Fea. A), two trash pits (Feas. B and C), and from a Feature E. Additional excavations were carried out at this site under the supervision of Dr. Edward B. Jelks, Department of Anthropology, Illinois State University, Normal, during the summers of 1972 and 1975-1976. Material recovered in 1976 has yet not been completely processed, so animal bone and shell recovered in 1976 will be analized and reported at some future date. The number of bone pieces examined from all excavations through the 1975 field season totaled 8122; at least 53 vertebrate species and 302 individual animals were represented (Table 1).

From her analyses of lithic and ceramic materials and feature distribution and content, Schilt (1977:177) has inferred that the Noble-Wieting site ''. . .was occupied ca. A.D. 1200 by a small community of hunter-gathers and horticulturists in the Upper Mississippian Langford Tradition . . . and the length of occupation is roughly estimated at 60 to 90 years . . .'' The village surface area is estimated to have covered ca. 2.75 acres (11,129m^2) and, excluding the former burial mound and possible plaza, 306m^2 have been excavated (Schilt, 1977:182). This represents slightly less than 4% of the total possible faunal bearing area of the site.

ACCOUNTS OF SPECIES

Mollusks

A total of 110 valves of freshwater mussels, representing at least 12 species, were recovered at this site (Table 2). All were typical in size and form of those occurring in creeks and small rivers such as Kickapoo Creek. The meat of these bivalves was probably eaten and certain shells, judging from six that had the posterior margins ground down at an angle, were used on occasion as some form of scraper. A section of one large specifically unidentified valve (probably *Lampsilis ovata*) had been ground and smoothed and was part of shell that probably had served as a spoon or dipper.

Vertebrates

Representatives of all classes of vertebrates were encountered in the sample and at least 5 species of fish, 1 amphibian, 1 snake, 8 turtles, 18 birds and 20 species of mammals were represented (Table 3).

The extent to which fish were utilized in the diet of these people is somewhat problematical, although it appears that the fish fauna of Kickapoo Creek was exploited and that a few species provided at least an occasional supplement to the basic meat staple of deer and elk. However, fewer that 25 individual fish were represented in the sample and the food value derived from these would have been minor compared with that of mammals. A single element of a toad (*Bufo* sp.) and two snake vertebrae were found and may well represent the remains of animals occupying the area naturally; their presence was probably incidental to the human occupation of the site. Turtles, on the other hand, appear to have been of some significance in the food economy of these people compared with other aquatic forms. Only one plastron section of a turtle (pond terrapin) showed evidence of having been cut and none of the carapaces appeared to have been worked. Quite often the carapace of a turtle was used as a bowl or dish and was altered in varying degrees by scraping and cutting. It would appear that the primary use to which turtles were put by the occupants of this village was for food. At least 54 turtles were represented, all of them aquatic except four. Considering the small size of Kickapoo Creek and the probable limited numbers of aquatic forms (mussels, fish, turtles) inhabiting such a small stream, the Noble-Wieting Indians made good use of all aquatic resources that were available to them.

Bird remains accounted for less than 3% of the identified bone pieces. Of the 18 species identified, 4 were raptorial birds (hawks, eagle, and owls) and 2 were corvids; they may well have been taken for use in ceremonialism, as decorative objects (feathers and body parts), or for reasons other than food (Parmalee, 1977). In all probability birds were taken when encountered, but their apparent limited use may reflect their formal abundance and availability within the proximity of the site. Waterfowl would not have occurred commonly, even during migration, along a small stream such as Kickapoo Creek, so the paucity of duck and goose remains is not surprising. Of all the birds represented in the sample, the turkey (38 elements, 14 individuals) was the most significant avian species serving as a supplemental food resource. These 14 birds would have contributed an estimated 120 pounds of usable meat to the diet, assuming the average weight of 8.5 pounds of usable meat per bird as presented by White (1953) is accurate.

Mammals were by far the most significant animals used by these people for food and as a source of raw material in the manufacture of bone tools. Based on this sample, the white-tailed deer and elk provided the basic meat staple in the diet of these people. Their remains comprised 80% of all identified mammal elements; the majority of indeterminate large mammal bones were also probably from deer and elk. Smaller furbearers such as raccoon, beaver, striped skunk, otter and squirrels (*Sciurus*) were taken whenever encountered and together formed an important supplement to the basic meat diet of elk and deer. However, with at least 20 beaver and 17 raccoons represented in the faunal sample (combined ca. 200 elements), there is an indication that these two animals may have been especially prized as a source of hides and meat and that intensive hunting efforts were made to obtain them. Certain bones of the two large herbivores

Table 1. Summary of the number of vertebrate species and remains represented at the Noble-Wieting Site.

Vertebrate Group	Total no. of pieces	% of total	No. of species	MNI	% of MNI
Fishes	399	4.88	5	21	6.95
Amphibians	1	.01	1	1	.33
Snakes	2	.02	1	1	.33
Turtles	224	2.71	8	54	17.88
Birds	200	2.40	18	45	14.90
Mammals	7296	89.76	20	180	59.60
Total	8122	99.78	53	302	99.99

Table 2. Freshwater mussels recovered at the Noble-Wieting Site

Species	Number of valves
Amblema plicata, Three-ridge	40
Elliptio dilatatus, Spike	11
Fusconaia flava, Pig-toe	1
Pleurobema cordatum	1
Anodonta grandis, Floater	7
Anodontoides ferussacianus, Cylindrical paper-shell	1
Actinonaias carinata, Mucket	3
Lampsilis radiata siliquoidea, Fat mucket	33
Lampsilis anodontoides fallaciosa, Slough sand shell	2
Lampsilis ovata ventricosa, Pocketbook	5
Lampsilis sp.	1
Ligumia subrostrata, Pond mussel	1
Ligumia recta, Black sand shell	4
Total	110

were used in the manufacture of various tools and utensils. Two proximal ends of elk metatarsals (cannon bone) were recovered that had been altered and used as a fleshing tool (beamer). The sharpened edges of this lower leg bone tool were used to scrape excess fat and tissue from hides. Three sections of this same element from the white-tailed deer had also been cut in a like manner.

Butchering cuts were noted on several deer and elk elements and are indicative of the manner in which the carcasses were disarticulated. In the case of deer bones, cuts noted on 5 tarsals, 8 astragali, 2 calcanea and the distal end of 2 tibiae resulted from an effort to cut through the hock joint while removing the hind foot. Scored marks on or near the rim of 5 acetabula suggest that the hind limb was generally separated from the pelvis by disarticulating the femur head from the socket. Butchering marks on the proximal end of 5 radii and 3 ulnae and the distal ends of 9 humeri resulted from severing of the forelimb at the ''elbow''. Two atlas, two axis, and the basioccipital of a skull exhibited cut marks; these occurred when the head was being removed from the body. From the numerous recovered skull sections (frontal bone), 3 could be determined as those of does and 9 as bucks. All of these male skulls, with the possible exception of one, had portions of the antler still attached; this would indicate that these particular individuals were killed in the fall or early winter season before the antlers are shed.

Of special interest was the cut distal end of a wolf humerus. This piece probably represents the discarded end of the bone since it was often common practice to cut off (groove-and-snap) both ends of a long bone and then utilize the main shaft as some sort of ornament or tool (Parmalee, 1976). Portions of a heavy bone ring were also encountered as well as a cut section of a beaver incisor; this latter tooth section was probably used as a scraper or chisel. The worked distal end of a turkey tarsometatarsus was recovered that had been sharpened and this tool probably functioned as an awl. Several other miscellaneous cut and scraped bones (e.g. a raccoon baculum) and antler artifacts were also found at the site.

The quantity of elk remains recovered at the Noble-Wieting Site, compared with those of deer, is especially noteworthy because of their abundance (233 pieces; at least 24 individuals) and similar distribution within features. Although the total number of pieces of deer bone recovered (1344) and the Minimum Number of Individuals (MNI) represented (58) were greater than those of elk, the estimated pounds of usable meat realized from elk (8400) was notably more than that from the white-tailed deer (5800 pounds; estimates derived from live animal weights/pounds of usable meat: White, 1953). Elements of elk have been found in numerous other prehistoric sites in Illinois (e.g. Parmalee, 1961) and the Midwest in general, but compared with deer this large herbivore has been poorly represented in the archaeological record. It would appear that elk were either fairly numerous within the vicinity of the Noble-Wieting Site during its occupancy or that the site inhabitants made a special effort to hunt them over a wide area. Cory (1912:70) commented that ''Nearly all of the early travelers in Illinois refer to the abundance of large game including Elk.''

Because of the relative numbers of deer and elk represented in the Noble-Wieting faunal sample and because of the size of these animals and, therefore, the quantity of meat they provided, it is apparent that these two herbivores comprised the bulk of the meat consumed. Nevertheless, smaller animals such as the beaver and raccoon formed a valued meat supplement in the diet and were undoubtedly hunted or trapped with some degree of regularity. Although a variety of other species are represented in the faunal sample from Noble-Wieting, there were only one or a very few individuals of each represented (e.g., gray fox, mink, muskrat, badger, otter) and this low frequency of occurrence very possibly reflects the formal local abundance of these animals.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Rose Schilt and Dr. Edward B. Jelks, Illinois State University, Normal, for the opportunity to study the Noble-Wieting Site faunal materials and for providing information about the site excavations and cultural complexities. A special note of gratitude is given to Mrs. Betty Creech for typing the manuscript.

Table 3. Vertebrates identified from the Noble-Wieting Site

Species	No. of bones	% of bones	Min. no individ
FISHES	399	4.88	21
Gar, *Lepisosteus* sp.	1	.01	1
River Redhorse, *Moxostoma carinatum*	1	.01	1
Redhorse, *Moxostoma* sp.	43	.53	6
Suckers: Family Catostomidae	44	.55	7
Channel Catfish, *Ictalurus* cf. *punctatus*	6	.07	2
Bullhead, *Ictalurus* sp.	8	.09	3
Sunfish/Crappie/Bass: Family Centrarchidae	2	.02	1
Indeterminate Fish	294	3.62	—
AMPHIBIANS	1	.01	1
Toad, *Bufo* sp.	1	.01	1
REPTILES (snakes)	2	.02	1
Snake: Family Colubridae	2	.02	1
REPTILES (turtles)	224	2.71	54
Snapping Turtle, *Chelydra serpentina*	31	.38	8
Musk Turtle, *Sternothaerus odoratus*	17	.21	5
Blanding's Turtle, *Emydoidea blandingi*	30	.36	7
Eastern Box Turtle, *Terrapene carolina*	34	.41	4
Map Turtle, *Graptemys* cf. *geographica*	3	.03	1
cf. Map Turtle, *Graptemys* sp.	1	.01	1
Painted Turtle, *Chrysemys picta*	6	.07	3
Red-eared Turtle, *Chrysemys scripta*	2	.02	2
Painted Turtle/Slider group, *Chrysemys* sp.	53	.65	14
Softshell Turtle, *Trionyx* sp.	8	.09	2
Indeterminate Turtle	39	.48	7
BIRDS	200	2.40	45
Pied-billed Grebe, *Podilymbus podiceps*	2	.02	2
Great Blue Heron, *Ardea herodias*	1	.01	1
Canada Goose, *Branta canadensis*	1	.01	1
Mallard, *Anas platyrhynchos* &/or Black Duck, *A. rubripes*	3	.03	3
Teal, *Anas* sp.	1	.01	1
Duck, *Anas* sp.	4	.05	1
Redhead, *Aythya americana*	1	.01	1
Duck spp.	11	.14	4
Hooded Merganser, *Lophodytes cucullatus*	1	.01	1
Cooper's Hawk, *Accipiter cooperii*	1	.01	1
Red-shouldered Hawk, *Buteo lineatus*	2	.02	2
Hawk sp.	3	.03	1
Bald Eagle, *Haliaeetus leucocephalus*	1	.01	1
Prairie Chicken, *Tympanuchus cupido*	1	.01	1
Turkey, *Meleagris gallopavo*	38	.47	14
Sandhill Crane, *Grus canadensis*	2	.02	2
Barred Owl, *Strix varia*	2	.02	2
cf. Red-headed Woodpecker, *Melanerpes erythrocephalus*	1	.01	1

Common Raven, *Corvus corax*	2	.02	2
Common Crow, *Corvus brachyrhynchos*	1	.01	1
cf. Dickcissel, *Spiza americana*	1	.01	1
Passerine sp.	1	.01	1
Indeterminate Bird	119	1.46	—
MAMMALS	7296	89.76	180
Opossum, *Didelphis marsupialis*	2	.02	1
Eastern Mole, *Scalopus aquaticus*	2	.02	1
Eastern Cottontail, *Sylvilagus floridanus*	2	.02	2
Eastern Chipmunk, *Tamias striatus*	23	.28	7
Fox Squirrel, *Sciurus niger*	13	.16	5
Squirrel, *Sciurus* sp.	37	.45	8
Plains Pocket Gopher, *Geomys bursarius*	3	.03	3
Beaver, *Castor canadensis*	107	1.32	17
Deer Mouse, *Peromyscus* sp.	1	.01	1
Muskrat, *Ondatra zibethica*	5	.06	3
Small Rodent sp.	4	.05	3
Gray Wolf, *Canis* cf. *lupus*	21	.26	3
cf. Domestic Dog, *Canis familiaris*	41	.50	9
Gray Fox, *Urocyon cinereoargenteus*	1	.01	1
Raccoon, *Procyon lotor*	96	1.18	20
Mink, *Mustela vison*	1	.01	1
Badger, *Taxidea taxus*	1	.01	1
Striped Skunk, *Mephitis mephitis*	12	.14	6
River Otter, *Lutra canadensis*	2	.02	2
Bobcat, *Lynx rufus*	5	.06	4
Elk, *Cervus elaphus*	233	2.87	24
White-tailed Deer, *Odocoileus virginianus*	1344	16.54	58
Deer/Elk: Family Cervidae (Indet. antler pieces)	6	.17	—
Indeterminate Large Mammal	4893	60.24	—
Indeterminate Small Mammal	441	5.43	—
TOTAL	8122	99.78	302

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The Distribution of the Fulgoroidea of the Eastern United States (Homoptera)

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ABSTRACT

The distributions of planthoppers occurring in the United States east of the Mississippi River are listed.

Metcalf's catalogue of the Fulgoroidea [Fascicle IV of the catalogue of the Homoptera (Hemiptera)] was published in 18 parts between 1932 and 1958. Those parts dealing with the eastern U. S. species of the Fulgoroidea (or planthoppers) were published between 1936 and 1958 (i.e., 1936; 1943; 1945; 1946; 1947a, b; 1954a, b; 1957; 1958) and have served as the basic source of information (e.g., synonyms, distributions, references) for these species. However, the distributions of these species as listed in Metcalf's catalogue have become increasingly outdated because of subsequent faunal lists, revisions of higher taxa, and descriptions of new species. Presented here are the updated distributions of the eastern U.S. species. These consist of the distributions given by Metcalf, supplemented with more recent records. We have omitted Metcalf's distributions for those taxa that have undergone revisions subsequent to publication of his catalogue. Only 1 reference is listed per state even though several authors may have provided records. The eastern U. S., as defined here, is that area east of the Mississippi River, and includes Louisiana and Minnesota which lie partially east of the River.

The present list includes 394 species in 89 genera and 10 families (Table 1). The sequence of taxa follows, where possible, that given in Metcalf's catalogue. *Delphacodes* has been split into several new genera by European workers [e.g., Fennah (29)] but we have elected to use the name *Delphacodes* because, apparently, few of the ca. 120 North American species were examined by these authors when they erected the new genera.

Table 1., List of the Fulgoroidea of the eastern United States.

Family *CIXIIDAE* Spinola

Pintalia Stal
delicata (Fowler), VA, SC, MS, LA (41).
dorsovittatus (Van Duzee), VA, SC, FL, TN (23); IL (64).
Oliarus Stal[a]
aridus Ball, VA, SC, GA, AL, MS, LA, TN, OH, IN, IL (38).
chuliotus Ball, DC, NC, SC, GA, FL, MS, IL (38).
cinnamomeus Provancher, ME, NH, MA, CT, NY, NJ, PA (38).
complectus Ball, FL (38).

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difficilis Van Duzee, FL (38).
ecologus Caldwell, CT, NJ, PA, MD, DC, VA, NC, SC, GA, AL, MS, TN, KY, OH, IL (38).
humilis (Say), NH, MA, CT, NY, NJ, PA, OH, IL, MI, WI, MN (38).
littoralis Ball, FL (38).
montanus Metcalf, NY, PA, MD, VA, NC, GA, TN, OH, IL (38).
placitus Van Duzee, NJ, MD, DC, VA, NC, SC, GA, FL, AL, OH, IL (38).
quinquelineatus (Say), ME, MA, CT, NY, NJ, PA, MD, VA, NC, SC, GA, FL, MS, IN, IL, WI, MN (38).
sablensis Caldwell, NH,MA,CT,NY,NJ,PA,MD,DC,WV,NC,SC,GA,FL,TN,KY,OH,IN,IL, MN (38).
slossonae Van Duzee, FL (38).
vicarius (Walker), NC, SC, GA, FL, (38).
viequensis Caldwell, FL (38).

Monorachis Uhler
sordulentus Uhler, FL, MS (41); IL (64).

Myndus Stal
crudus Van Duzee, FL (36).
dozieri Kramer, MS (36).
enotatus Kramer, MD, VA, NC, SC, GA, FL, MS, LA (36).
fulvus Osborn, NY, TN, KY, OH (36); IL (64).
glyphis Kramer, MA, NY, TN (36).
lunatus Van Duzee, FL (36).
neopusillus Kramer, FL (36).
ovatus Ball, MA, NJ, MD, VA, GA (36).
pictifrons Stal, MA, CT, NY, NJ, PA, MD, VA, NC, GA, MS, LA, TN, OH, IN,IL(36).
pusillus Van Duzee, NH, MA, CT, NJ, VA, NC, GA, FL (36).
radicis Osborn, NY, MD, VA, NC, MS, OH, IN, IL (36).
slossonae Ball, GA, FL, MS (36).
truncatus Metcalf, IL, WI (36).
xyron Kramer, NY, MI (36).

Cixius Latreille
angustatus Caldwell, OH (21).
apicalis Metcalf, CT, NY, (41); OH (56).
coloepeum Fitch, ME, NH, CT, NY, NJ, PA (41); NC (20); OH (41); IL (64).
misellus Van Duzee, ME, NH, MA, RI, CT, NY, NJ, PA, NC, GA, KY, OH, IL, MI (41).
nervosus (Linnaeus)[b], ME, NH, MA, RI, CT, NY, NJ, GA, OH (41); IN (31); IL (64).
pini Fitch, ME, NH, MA, CT, NY, NJ, PA, NC (41); OH (56); IL (64); MI (41).
stigmata (Say)[c], NH, NY, NJ, PA, GA, OH (41); IN (31); IL (64).
umbrosus Walley, OH (56).

Oecleus Stal
borealis Van Duzee, NY, NJ, PA, MD, SC, GA, FL, MS, AL, OH, IL, MI (34).
chrisjohni Kramer, IL (63).
epetrion Kramer, IL (63).
productus Metcalf, MD, GA, FL, MS, IL (34).
tamiamus Ball and Klingenberg, FL (34).

Nymphocixia Van Duzee
vanduzeei Muir, FL (24).

Bothriocera Burmeister
bicornis (Fabricius), NJ, MD, NC, FL (41).
cognita Caldwell, MS (22).
drakei Metcalf, FL (39), OH (22).
furcata Caldwell, FL (22).
maculata Caldwell, FL (22).

signoreti Stal, MD, GA, FL (41), IL (64).
transversa Caldwell, FL (22).
undatus (Fabricius), NC (20), FL (41).

Family *DELPHACIDAE* Leach

Copicerus Swartz
irroratus Swartz, FL, MS, OH (42); IL (61).
Pentagramma Van Duzee
douglasensis Penner, MI (58).
longistylata Penner, FL (58).
variegata Penner, NY, MS, IN, IL, MN (58).
vittatifrons (Uhler), NJ, NY, MD, VA, IL (58).
Stobaera Stal
affinis Van Duzee, FL (33).
concinna (Stal), FL, LA (33).
pallida Osborn, NY (33); NJ (26); MD, VA, FL (33).
tricarinata (Say), MA, NY, NJ, PA, MD, VA, NC, SC, GA, FL, MS, AL, LA, TN, OH, IN, IL, MN (33).
Liburniella Crawford
ornata (Stal), ME, MA, CT, NY, NJ, PA, DC, NC, SC, GA, FL, MS, AL, LA, KY, OH, IN, IL, MN (42).
Laccocera Van Duzee
vittipennis Van Duzee, NH, NY, MI, MN (57).
Achorotile Fieber
albosignata (Dahlbom), NY[d] (42).
Phyllodinus Van Duzee
nervatus Van Duzee, NY, MI (52).
Stenocranus Fieber
acutus Beamer, NC, GA, FL, MS (3).
arundineus Metcalf, NC, GA (3).
brunneus Beamer, IL (3).
delicatus Beamer, IL (3).
dorsalis (Fitch), ME (3), IL (61).
felti Van Duzee, NH, WI, MN (3).
lautus Van Duzee, NH, NY, MD, DC, VA, NC, IL (3).
pallidus Beamer, IL, WI (3).
ramosus Beamer, NC, GA, FL (3).
sandersoni Beamer, IL (5).
similis Crawford, KY (3), IL (64).
unipunctatus Provancher, IL (64).
Kelisoidea Beamer
versa Beamer, FL (13).
Kelisia Fieber
axialis Van Duzee, NH, VT, NY, PA, VA, WI (16).
bimaculata Beamer, NH (16), WI (2).
curvata Beamer, MD, DC (2); NC (16); GA (2); FL (16); OH (2); IL (64).
flava Beamer, NH, CT, NY, PA (16); MD (26); NC (16).
hyalina Beamer, IL (61).
parvicurvata Beamer, FL (16).
pectinata Beamer, IL (16).
retrorsa Beamer, NH, CT, PA (16); IL (61); MI, MN (2).

spinosa Beamer, CT (2); PA (16); IL (64); MI, WI (2).
torquata Beamer, CT (16).
vesiculata Beamer, CT (16).

Megamelus Fieber
aestus Metcalf, NH (18), NC (20).
bifidus Beamer, NY (18).
davisi Van Duzee, NY (42); NJ (18); PA, DE (42); DC (18); NC (42); FL, TN (18); OH (42); IL, MI (18).
distinctus Metcalf, CT, NY, IL, MI (18).
falcatus Beamer, NH, CT, NY (18).
gracilis Beamer, FL (18).
hamatus Beamer, MD, VA (18).
inflatus Metcalf, NY (18).
lobatus Beamer, NH, CT, NJ, MD, GA, FL, MS, LA (18).
longicornis (Dozier), LA (18).
lunatus Beamer, NY (18); IL (61).
metzaria Crawford, NH, NY, (18); IL (61); MI (18).
palaetus (Van Duzee), FL, LA (18); IL (62).
toddi Beamer, LA (18).
trifidus Beamer, FL (18).
ungulatus Beamer, CT, NC, (18).

Bakerella Crawford
angulata Beamer, FL (12).
bullata Beamer, MD, FL, LA (12).
cornigera Beamer, PA, VA (12).
minuta Beamer, GA, FL (12).
muscotana Beamer, IL (12).
pediforma Beamer, FL, MS, LA (12).
penefusca Beamer, NH, CT, PA (12).
rotundifrons Beamer, IL (61).
spinifera Beamer, GA (12).

Bostaera Ball
balli Penner, NC, GA, FL (59).

Pissonotus Van Duzee
agrestis Morgan and Beamer, CT, GA, FL (52).
albivultus Morgan and Beamer, FL (52).
albovenosus Osborn, NJ (26); VA (52); SC (26); FL, LA (52); IL (64).
aphidioides (Van Duzee), CT, NY (52).
aguilonius Morgan and Beamer, IL (64), WI (52).
basalis (Van Duzee), NY, PA, OH (52).
binotatus Spooner, VA, NC, GA, FL (52).
brunneus Van Duzee, NH,MA,CT, NY, PA, MD, DC, VA, NC, FL, MS, LA, OH, IL, WI (52).
delicatus Van Duzee, NY, FL (52); IL (64).
dentatus Morgan and Beamer, FL (52), IL (61).
dorsalis Van Duzee, CT, NY, WI (52).
flabellatus (Ball), NY, DC, VA, FL, OH, IL (52).
guttatus Spooner, NH, CT, NY, MD, DC, OH (52); IL (61).
marginatus Van Duzee, NY, VA, FL, OH, IL, MI (52).
merides Morgan and Beamer, FL, MS, AL (52).
niger Morgan and Beamer, CT, NY, IL, MI (52).
nigriculus Morgan and Beamer, FL (52).
nigridorsum Metcalf[e], PA (42).
nitens (Van Duzee), FL (52).

paludosus Morgan and Beamer, FL, MS, AL, LA (52).
piceus (Van Duzee), NY, IL, MI (52).
quadripustulatus (Van Duzee), GA, FL (52).
spooneri Morgan and Beamer, NY (52).
tessellatus (Ball), FL, MS, OH (52).
tumidus Morgan and Beamer, NH, CT, NY, PA, MI (52).

Saccharosydne Kirkaldy
saccharivora (Westwood), GA, FL (42).

Dicranotropis Fieber
incerta (Van Duzee), NY, OH (42).

Pareuidella Beamer
avicephaliforma Beamer, GA, FL, LA (14).
spatulata Beamer, NC, GA, FL (14).

Euides Fieber
gerhardi (Metcalf), IL (42).
magnistyla (Crawford), GA (42).
triloba (Metcalf), FL, LA (42).
vanduzeei (Muir and Giffard), FL, MS, LA (42).
weedi (Van Duzee), GA, FL, MS (42); IL (64).

Peregrinus Kirkaldy
maidis (Ashmead), DC, NC, SC, FL, AL, LA TN, OH (42); IL (42[f], 61).

Penepissonotus Beamer
bicolor Beamer, MD, VA, NC, GA, FL (14).

Neomegamelanus McDermott
dorsalis (Metcalf), NY, NJ, MD, FL, MS, LA (37).
elongatus (Ball), CT, NY, MD, VA, FL, MS, LA (37).
lautus (Metcalf), MS (39), LA (37).
penilautus McDermott, FL (37).
spartini (Osborn), ME, NY, MD, NC, FL, MS, OH (42).

Megamelanus Ball
rufivittatus Ball, GA (37).

Prokelisoidea McDermott
salina (Ball), IL (61).

Tumidagena McDermott
minuta McDermott, CT, NY (37); NJ (26); MD (37).
propinqua McDermott, MS, LA (37).
terminalis (Metcalf), NC (39), FL (37).

Prokelisia Osborn
crocea (Van Duzee), ME, MA, CT, OH (42); IL (61).
marginata (Van Duzee), MA, CT, NY, NJ, NC (42); SC, GA (26); FL, MS, IL[d] (42).
setigera Osborn, MA, NY, MS, LA (42).

Chloriona Fieber
slossoni (Ball), GA, FL, MS, LA (4); IL (61); MI (4).

Rotundifronta Beamer
lutea Beamer, FL (13).

Macrotomella Van Duzee
carinata Van Duzee, FL (42), IL (61).

Criomorphus Curtis
conspicuus Metcalf, MA, CT, IL (42).
inconspicuus Uhler, NY[d] (42).

Keyflana Beamer
hasta Beamer, MD (26), FL (13).

Delphacodes Fieber
aculeata Beamer, FL (9).

acuministyla Dozier, CT, VA, MS (15).
adunca Beamer, NC, FL (9).
aetocephala Beamer, FL, MS, LA (9).
alata Beamer, FL (10).
alexanderi (Metcalf), NC, GA, FL, TN (28); IL (64).
analis (Crawford), NY, NC (28); IL (61); MI, MN (28).
andromeda (Van Duzee), NC, FL (28); IL (64).
arcanastyla Beamer, MI, WI (9).
arcuata Beamer, FL (9).
ardentis Beamer, FL (10).
arvensis (Fitch), NY, NJ (42).
atralabis Beamer, NH (9).
atrata Osborn, NH, NY, CT, OH, IL (15).
balli Muir and Giffard, CT (53).
basivitta (Van Duzee), NH, MA, CT, NY, PA, VA, NC, GA, FL, TN, IN, IL (28).
campestris (Van Duzee), NH, CT, (28); NY, NJ (55); NC (28); MS (55); IL (28); MI (55).
concava Beamer, GA, FL (10).
consimilis (Van Duzee), DC, NC (28).
cornuta Beamer, FL (9).
culta Van Duzee, FL (42).
dentipennis Beamer, CT, VA, (9); NC (28); WI (9).
detecta (Van Duzee), CT, NY (11); MD (28); VA (11); NC, FL, LA (28).
dolera (Spooner), NY, VA, IL (15).
floridae Muir and Giffard, FL (53).
foveata (Van Duzee), NY (55), IL (64).
fulvidorsum Metcalf, GA, FL (4).
furcata (Provancher), NH, NY (53).
humilis (Van Duzee), FL (42).
hyalina Beamer, IL (61).
idonea Beamer, FL (7).
incurva Beamer, CT (8).
indentistytla Dozier, MS (42).
kilmani (Van Duzee), NH (28); NY (55); NC, MI (28).
laminalis (Van Duzee), NY (55); PA, MD, DC, NC, FL (28); MS (55); IN (28); IL (61).
lineatipes (Van Duzee), NY, PA, NC, OH (28).
livida Beamer, CT (8).
lutea Beamer, IL (61)
lutulenta (Van Duzee), NH, CT, NY, NC (28); IL (64).
magna (Crawford)[g], IL (61).
mcateei Muir and Giffard, MD (53); IL (61).
nigridorsum (Crawford), NY, NJ, OH (42).
nigripennata Beamer, NC (28), FL (6).
nitens Muir and Giffard, MD, OH (53); IL (64).
obscurella Boheman, NY[d] (42).
opaca Beamer, CT, PA, VA (8).
pacifica (Crawford), IL (64).
paransera Beamer, NY (9).
paraparvula Beamer, MS (10).
parvula (Ball), IL (61).
pellucida (Fabricius), ME, NH, MA, CT, NC, IL (28).
penedetecta Beamer, FL, LA (11).
penelutea Beamer, FL, MS (10).
peneparvula Beamer, KY (7).
penepuella Beamer, NY, FL (8).

perusta Beamer, NY, OH (7); IL (61).
pictifrons Osborn, OH (42).
propinqua (Fieber), NC (28), IL (61).
puella (Van Duzee), NH, CT (28); NY, NJ (55); NC, FL (28); MS (55); TN, OH, IL (28).
quadridentis Beamer, FL, MS (9).
recurvata Beamer, DC (8); NC (28); FL (8).
rivularis (Germar), GA (42).
rotundata (Crawford), NY, NJ, NC (28); IL (61).
sagae Beamer, NY (6), IL (64).
sagittata Beamer, GA (7).
seminigra (Stal), FL (42).
serrata Beamer, CT, NY (8).
shermani (Metcalf), NC (28).
staminata (Metcalf), IL (47).
stramineosa Beamer, CT, NY (8).
sucinea Beamer, FL, MS (10).
teapae (Fowler), FL (42).
trimaculata Beamer, CT, MD, DC, VA (8); IL (64).
truncata Beamer, VA, GA, FL, MS, LA (9).
turgida Beamer, GA, FL, (9).
uhleri Muir and Giffard, VA (42).
unda Metcalf, NC (42).
waldeni (Metcalf), CT (47).
wetmorei Muir and Giffard, NC, GA (28).

Sogata Distant
breviceps Dozier, MS (42).
pseudoseminigra Muir and Giffard, FL (53).

Sogatella Fennah
kolophon (Kirkaldy), GA, FL (17).

Sogatodes Fennah
orizicola (Muir), FL, MS, LA (1).

Family *DERBIDAE* Spinola

Euklastus Metcalf
harti Metcalf, NC, IL (43).

Mula Ball
resonans Ball, FL, MS (43).

Mysidia Westwood
mississippiensis Dozier, FL, MS, LA (43).

Patara Westwood
vanduzei Ball, ME (60); NY, PA, NC, OH (43); IL (64).

Omolicna Fennah
fulvus (Van Duzee), FL (43).
mcateei (Dozier), NC (65), MS (43).
uhleri (Ball), NY, NJ, MD, DC, VA, NC, GA, MS, TN, OH (43); IL (64).

Neocenchrea Metcalf
heidemanni (Ball), MD, DC, VA, NC, OH (43); IL (64).

Dysimia Muir
maculata Muir, FL (43).

Cedusa Fowler[h]
australis (Metcalf), MS, IL, MI (30).
bedusa McAtee, VA, NC, FL, MS, LA (30); IL. (64).
californica (Van Duzee), MI (30).

cedusa McAtee, NY, MD, VA, MI, MN (30).
chuluota Ball, NC, GA, FL (30).
edentula (Van Duzee), NJ, VA, NC, GA, MS, TN (30); IL (61).
gedusa McAtee, MD, MS, TN (30).
hedusa McAtee, NY, MD, SC, GA (30).
incisa (Metcalf), NH, CT, NY, NC, OH, IN, IL, MI, MN (30).
kedusa McAtee, NJ, MD, VA, NC, OH, IL, MI, WI (30).
maculata (Van Duzee), NC, IN, MN (30); IL (64).
mallochi McAtee, MD, VA, NC, FL, MS, IN, IL (30).
minuenda Ball, NC, FL (30).
neomaculata Caldwell, FL (30).
obscura (Ball), ME, CT, VA, NC, GA, FL, MS, IL, MI, WI (30).
redusa McAtee, MD, VA, NC, FL, KY (30).
vulgaris (Fitch), CT, VA, NC, GA, IL, MI (30).

Sayiana Ball
sayi (Ball), NY, FL (43); IL (64).

Amalopota Van Duzee
fitchi Van Duzee, NY, PA, NC, GA, FL, MS, TN, OH (43); IL (64).
mcateei Dozier, MS (43), IL (64).
uhleri Van Duzee, NY, FL, MS, TN, OH, IN, IL, MN (43).

Anotia Kirby
bonnetii Kirby, CT, NY, NJ, NC, GA, FL (43); IL (64).
burnetii Fitch, NY, PA, NC, MS, IN, IL, (43).
kirkaldyi Ball, PA, NC, MS (43); IL (64).
robertsonii Fitch, NJ, PA, FL (43).
westwoodii Fitch, NY, NJ, PA, NC, OH (43); IL (61).

Otiocerus Kirby
abbotii Kirby, CT, NY, NC, GA, FL, OH, IN, (43), IL (64); MN (43).
amyotii Fitch, CT, NY, NJ, PA, DC, NC, GA, OH (43); IL (64).
coquebertii Kirby, NH, MA, CT, NY, NJ, PA, MD, NC, OH, IN, IL, MN (43).
francilloni Kirby, NY, NJ, GA, FL, OH (43); IL (64).
kirbyii Fitch, NY, NC, MS, AL (43).
reamurii Kirby, NY, GA, OH (43).
signoretii Fitch, NY, NJ, PA (43).
stollii Kirby, NY, NJ, PA, NC, GA, FL, MS, LA, OH, (43); IL (64).
wolfii Kirby, NY, NJ, PA, MD, NC, GA, FL, MS, OH, IL (43).

Apache Kirkaldy
degeerii Kirby, ME (60); NH, MA, CT, NY, NJ, PA, MD, NC, GA, FL, MS, LA, TN, OH, IN, IL, MN (43).

Shellenius Ball
ballii (McAtee), MD, FL, MS, OH (43); IL (64).
schellenbergii (Kirby), NY, NJ, GA, FL, MS, OH (43); IL (64).

Family *DICTYOPHARIDAE* Spinola

Nersia Stål
florens Stål, SC, GA, FL, MS (44); IL (64).
florida Fennah, FL (44).

Mitrops Fennah
dioxys (Walker), NJ, MD, MS (44).

Rhynchomitra Fennah
lingula (Van Duzee), NY, NJ, NC, SC, FL, MS (44).
microrhina (Walker), NY, NJ, NC, SC, FL, MS, LA (44); IL (64).
recurva (Metcalf), NC (39).

Phylloscelis Germar
atra Germar, MA, CT, NY, NJ, PA, MD, DC, VA, NC, SC, GA, FL, MS, TN, OH, IN, IL (44).
pallescens Germar, MA, NY, NJ, PA, MD, NC, FL, MS, OH (44); IL (64).
rubra Ball, NY, NJ, FL, MS (44).
Scolops Schaum
angustatus Uhler, MA, CT, NY, NJ, MD, DC, NC, GA, FL, MS, LA, OH, IN (44); IL (64); MN (44).
grossus Uhler, NJ[d], IL[d] (44).
hesperius Uhler, MA[d] (44).
osborni Ball, OH[d] (44).
perdix Uhler, MA, NY, NJ, MD, DC, VA, NC, SC, FL, MS, OH, IL (44).
pungens (Germar), CT, NY, NJ, PA, MD, DC, NC, SC, FL, MS, LA, KY, OH, IL, WI (44).
stonei Breakey, NC, GA, FL, MS (44).
sulcipes (Say), ME, VT, MA, RI, CT, NY, NJ, PA, MD, DC, VA, NC, FL, MS, KY, OH, IN, IL, MI, WI, MN (44).
uhleri Ball, NC[d] (20).

Family *FULGORIDAE* Dumeril

Poblicia Stål
fuliginosa (Olivier), NC, MS, OH (45); IL (64).
Calyptoproctus Spinola
marmoratus Spinola, GA, MS (45).
Cyrpoptus Stål
belfragei Stål, MD, VA, NC, SC, FL, MS, AL, TN (35); IL (64).
reineckei Van Duzee, NC, (20); SC, GA, FL, MS, AL (35).
Alphina Stål
glauca (Metcalf), MS (45).
Amycle Stål
vernalis Manee, NC, GA (45).

Family *ACHILIDAE* Stal

Catonia Uhler
bicinctura Van Duzee, NC, GA, FL, OH, MI (54).
carolina Metcalf, MD, VA, NC, SC, GA, FL, TN, OH, IL (54).
cinctifrons (Fitch), NH, MA, CT, NY, NJ, PA, DE, MD, VA, NC, SC, GA, FL, OH (54); IL (64).
lunata Metcalf, NJ, MD, VA, NC, SC, GA, FL, MS, AL, OH (54).
nava (Say), NY, MD, VA, NC, GA, FL, MS, LA, OH, IN (54); IL (64).
picta Van Duzee, CT, NJ, VA, NC, GA, FL, MS, AL (54).
pini Metcalf, NC, GA, FL, MS, LA (54).
pumila Van Duzee, NH, MA, NY, NJ, PA, MD, VA, NC, SC, GA, AL, LA, TN, OH, IN (54); IL (64); MN (54).
Opsiplanon Fennah
luellus (Metcalf), GA, FL (54).
Synecdoche O'Brien
dimidiata (Van Duzee), ME, NH, RI, CT, NY, NJ, PA, MD, VA, WV, NC, GA, FL, OH (54).
grisea (Van Duzee), CT, NY, PA, MD, VA, NC, KY, OH (54); IL (61); MI (54).
impunctata (Fitch), ME, NH, MA, CT, NY, NJ, PA, VA, WV, NC, GA, TN, OH, IN, IL, MI (54).
Epiptera Metcalf
brittoni Metcalf, CT, NY, NC (46).
colorata (Van Duzee), NY (46).
fusca (Walker), RI, NY, NJ, FL (46); MS (32).

opaca (Say), NH, MA, NY, NJ, PA, MD, NC, SC, GA, MS, TN, OH, IN (46); IL (64).
pallida (Say), NH, NY, NJ, PA, DC, FL, MS (46).
septentrionalis (Provancher), NH, NY, NJ (46).
slossoni (Van Duzee), NH, NY (46).
variegata (Van Duzee), ME, NH, CT, NY, NJ, VA, NC, OH (46); IL (64).

Family *TROPIDUCHIDAE* Stal

Neurotmeta Guerin-Meneville
sponsa (Guerin-Meneville), FL (48).
Pelitropis Van Duzee
rotulata Van Duzee, NC, FL, MS (48).
Monopsis Spinola
tabida Spinola, FL (48).

Family *FLATIDAE* Spinola

Leptormenis Melichar
relicta Fabricius, NC, SC (50).
Ormenis Stal
proxima (Walker), FL (50).
Anormenis Melichar
chloris Melichar, NC (50).
septentrionalis (Spinola), CT, NY, NJ, PA, MD, DC, VA, NC, SC, GA, FL, MS, TN, OH, IN, IL (50).
Ormenoides Melichar
venusta (Melichar), VA, NC, SC, GA, FL, MS, TN, OH, IN (50); IL (64).
Metcalfa Caldwell and Martorell
pruinosa (Say), MA, RI, CT, NY, NJ, PA, DE, MD, DC, VA, NC, GA, FL, MS, LA, TN, KY, OH, IN, IL, MI, MN, (50).
Ormenaria Metcalf and Bruner
rufifascia (Walker), GA, FL (27).
Mistharnophantia Kirkaldy
sonorana Kirkaldy, FL (50).
Cyarda Walker
acuminipennis (Spinola), FL (50).
melichari Van Duzee, DC, NC, FL, MS (50); IL (64).
Flatoides Guerin-Meneville
concisa Metcalf, FL (50).
Flatoidinus Melichar
acutus (Uhler), GA, FL (50).
punctatus (Walker), GA, FL (50).
scabrosus (Melichar), GA (50).

Family *ACANALONIIDAE* Amyot and Serville

Acanalonia Spinola
bivittata (Say), ME,MA,CT,NY,NJ,PA,MD,DC,VA,WV,NC,SC,GA,FL,MS,AL,LA,KY, OH, IN, IL, MI, WI, MN (49).
concinnula Fowler, FL (49).
conica (Say), DE, MD, VA, NC, GA, FL, MS, AL, LA, TN, KY, OH, IN, IL (49).
latifrons (Walker), PA, NC, SC, GA, FL, MS, LA (49).

pumila (Van Duzee), NC, FL (49).
servillei Spinola, NY, PA, FL, LA (49).
virescens (Stål), FL (49).

Family *ISSIDAE* Spinola

Fitchiella Van Duzee
robertsonii (Fitch), NY, PA, MD, FL, MS, OH, IN, IL (51).
Bruchomorpha Newman
abrupta Ball, FL (51).
dorsata Fitch, CT, NY, NJ, PA, NC, MS, OH, IL, WI (51).
jocosa Stål, NJ, DC, VA, NC, SC, FL, MS (51); IL (64); WI (51).
minima Metcalf, NC, FL (51).
mormo Kirkaldy, NC[d] (51).
nodosa Doering, LA (51).
oculata Newman, ME, NH, VT, CT, NY, NJ, PA, MD, VA, NC, FL, MS, OH, IN, IL, WI, MN (51).
pallidipes Stål, DC, VA, SC, FL, MS, AL, LA (51); IL (64).
suturalis Melichar, NC[d], FL[d], MS[d] (51).
tenebrosa Doering, FL (51).
tristis Stål, CT, NY, NJ, DC, NC, FL (51); IL (64); WI, MN (51).
Aphelonema Uhler
decorata (Van Duzee), NJ, FL (51).
histrionica (Stål), NH, MA, NY (51); IL (61); MI, WI, MN (51).
nigriviridia Ball, FL (51).
obscura Van Duzee, GA, FL, MS (51).
rugosa (Ball), MD[d], MN (51).
simplex Uhler, CT, NJ, MD, VA, FL, MS, OH (51); IL (64).
viridis Dozier, MS (51).
Hysteropterum Amyot and Serville
fuscomaculosum Doering, FL (51).
punctiferum Walker, NJ, GA, FL (51).
Thionia Stål
bullata (Say), NY, NJ, PA, DC, NC, SC, GA, FL, MS, AL, LA, TN, OH, IN (51); IL (64).
elliptica (Germar), NJ, DC, NC, GA, KY, OH (51); IL (64).
quinquata Metcalf, NC, GA (51).
simplex (Germar), NJ, MD, DC, VA, NC, SC, FL, MS, AL, TN, KY, OH (51); IL (64).

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[a]plus 1 unpublished new species [see Mead (38)].
[b]synonym of *C. basalis* Van Duzee [see Beirne (19)].
[c]this species was placed in *Pseudocixius* by Caldwell (25). *Cixius* is currently being revised by J.P. Kramer (pers. comm.) and his review may change the placement of this species.
[d]record possibly in error.
[e]Morgan and Beamer (52) state that this species "is not a *Pissonotus*" but do not indicate in which genus it belongs.
[f]record in error [see reference listed in Metcalf (43)].
[g]may not be D. *magna* [see Wilson (61)].
[h]plus 6 unpublished new species [see Flynn (30)].
[i]Metcalf (50) listed locality as "Carolina".

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FOOTNOTE

A List of the Host Plants of the Illinois Acanaloniidae and Flatidae (Homoptera:Fulgoroidea)[1]

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ABSTRACT

A referenced list of the host plants of the acanaloniids *Acanalonia bivittata* (Say) and *A. conica* (Say), and the flatids *Anormenis septentrionalis* (Spinola), *Metcalfa pruinosa* (Say) and *Ormenoides venusta* (Melichar), is presented.

The superfamily Fulgoroidea contains ca. 860 species in 11 families in America north of Mexico (unpubl. data); all species studied are phytophagous (61). Of these, 9 families and 150 species occur in Illinois (61). Two of the 9 families, the Acanaloniidae and Flatidae, contain species that are common in Illinois (61). The family Acanaloniidae is represented by *Acanalonia bivittata* (Say) and *A. conica* (Say), the family Flatidae by *Anormenis septentrionalis* (Spinola), *Cyarda melichari* Van Duzee, *Metcalfa pruinosa* (Say) and *Ormenoides venusta* (Melichar). All but *C. melichari* are widely distributed in the state; *C. melichari* has been collected only in Monroe and Union Counties, and is represented by 5 specimens, 1 deposited in the Illinois Natural History Survey collection, 4 in the Entomology collection, Zoology Research Museum, Southern Illinois University at Carbondale.

Little life history information has been published for the Illinois acanaloniids and flatids, the exception being that of host plants. However, host plant records are scattered throughout numerous publications. Presented here is a summary of these records, including plant species that do not occur in Illinois (Table 1); not included are those of *C. melichari,* which has been recorded from beach grasses (31), shrubs, weeds, "wild tobacco" (*Nicotiana* sp.) (35) and lantana (*Lantana camara* Linnaeus) (26). ***A. bivittata*** has been found on 19 species in 12 families, ***A. conica*** on 22 species in 18 families, *A. septentrionalis* on 41 species in 26 families, *M. pruinosa* on 85 species in 45 families, and *O. venusta* on 5 species in 4 families (Table 1).

Table 1. List of host plants of the Illinois Acanaloniidae and Flatidae[a,b]

Family PINACEAE

Juniperus chinensis Linnaeus, Mp, 5 (N).

Family LILIACEAE

Convallaria majalis Linnaeus, As, 47.
Lilium longiflorum Thunberg, Mp, 5.
Lilium tigrinum Ker, Ac, 7.

[1]Part of a dissertation submitted to Southern Illinois University at Carbondale by the senior author in partial fulfillment of the requirements of the Ph.D. degree in Zoology.
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Family GRAMINEAE

Saccharum officinarum Linnaeus, Ab, 54[c].
Sorghum halapense (Linnaeus), Mp, 13, 22.
Zea mays Linnaeus, Ab, 23; Ac, 7, 9, 13, 33, 36, 39; As, 23; Mp, 13, 17, 23, 33, 44.

Family ARACEAE

Scindapsus aureus Engler, Mp, 5 (N).

Family ZINGIBERACEAE

Alpinia speciosa Dietrich, Mp, 5 (N).

Family JUGLANDACEAE

Carya glabra (Miller), As, 62 (A).
Carya illinoensis (Wangenheim), As, 9; Mp, 9, 25; Ov, 9.
Carya sp. Mp, 9, 23, 25
Juglans nigra Linnaeus, Ab, 34 (N, A); Ac, 34 (N, A); As, 34 (N,A), 62(N, A); Mp, 34(N, A), 38; Ov, 34(A).

Family SALICACEAE

Populus deltoides Marshall, Ab, 23.
Populus sp., Mp, 23.
Salix sp., As, 23; Mp, 23.

Family BETULACEAE

Alnus glutinosa (Linnaeus), As, 9, 36, 49, 52; Mp, 9, 49.
Betula sp., Mp, 9, 25, 43, 45, 49.
Carpinus caroliniana Walter, Mp, 23.
Corylus sp., Mp, 9, 49.
Ostrya virginiana (Miller), As, 62 (A).

Family FAGACEAE

Fagus grandifolia Ehrhart, As, 62.
Quercus illicifolia Wangenheim, Mp, 10.
Quercus sp., As, 9, 23, 36, 48 (N), 49; Mp, 9, 23, 25, 49, 63.

Family ULMACEAE

Celtis laevigata Willdenow, Mp, 5.
Celtis sp., Mp, 37, 49.
Ulmus americana Linnaeus, Ab, 19; Ac, 19; Mp, 19, 24; Ov, 19.
Ulmus rubra Muhlenberg, As, 62(N, A).
Ulmus sp., As, 23; Mp, 9, 25, 37 (N), 38, 45, 49.

Family MORACEAE

Ficus carica Linnaeus, Mp, 5 (N).
Ficus lyrata Warburg, Mp, 5 (N).

Humulus sp., Ac, 3, 33.
Maclura pomifera (Rafinesque), Ac, 3, 7, 9, 32, 36, 49; Mp, 3, 55.
Morus sp., Mp, 23.

Family POLYGONACEAE

Antigonon leptopus Hooker and Arnot, Mp, 5 (N).
Coccoloba uvifera Linnaeus, Mp, 25.
Rheum raponticum Linnaeus, Mp, 9, 11, 49.

Family PHYTOLACCACEAE

Phytolacca americana Linnaeus, As, 8.

Family NYCTAGINACEAE

Bougainvillaea spectabilis Willdenow, Mp, 5 (N).

Family CHENOPODIACEAE

Beta vulgaris Linnaeus, Ac, 7, 9, 36, 49; Mp, 9, 14, 49.

Family MAGNOLIACEAE

Liriodendron tulipfera Linnaeus, As, 47.
Magnolia sp., Mp, 25.

Family ANNONACEAE

Asimina triloba (Linnaeus), Mp, 9, 49.

Family LAURACEAE

Persea americana Miller, Mp, 5 (N).
Sassafras albidum (Nuttall), Mp, 3, 9, 49.

Family RANUNCULACEAE

Clematis virginiana Linnaeus, Mp, 3.

Family THEACEAE

Stewartia sp., Mp, 25.

Family PLATANACEAE

Platanus occidentalis Linnaeus, As, 23, 62.

Family HAMAMELIDACEAE

Liquidambar styraciflua Linnaeus, As, 9, 63 (A); Mp, 9.

Family SAXIFRAGACEAE

Deutzia sp., As, 47.

Family ROSACEAE

Crataegus sp., As, 9, 25, 36, 48 (N).
Prunus myrobalana Loiseleur, Ac, 28, 29; Mp, 28, 29.
Prunus persica (Linnaeus), Ac, 28, 29; As, 47; Mp, 25, 28, 29, 46.
Prunus virginiana Linnaeus, Mp, 50.
Pyracantha crenulata Roemer, Mp, 5 (N).
Pyrus malus Linnaeus, Ab, 23; As, 47; Mp, 3, 46; Ov, 36.
Ribes grossularia Linnaeus, Mp, 11.
Ribes sp., As, 47; Mp, 9, 49, 56.
Rosa sp., As, 47.
Rubus flagellaris Willdenow, Ab, 23.
Rubus sp., Ab, 23, 52; Mp, 14, 23.

Family LEGUMINOSAE

Bauhinia variegata Linnaeus, Mp, 5 (N).
Cercis canadensis Linnaeus, As, 62 (A).
Gleditsia triacanthos Linnaeus, As, 23.
Glycine max (Linnaeus), Ab, 2.
Medicago sativa Linnaeus, Mp, 17, 44.
Melilotus officinalis Linnaeus, As, 62 (N).
Prosopis sp., Mp, 58.
Robinia pseudoacacia Linnaeus, Ac, 16; Mp, 16.
Trifolium pratense Linnaeus, Mp, 37 (N), 45, 49.
Trifolium sp., Ab, 20, 23.
Vigna sinensis (Linnaeus), Ac, 7, 9.

Family EUPHORBIACEAE

Acalypha virginica Linnaeus, Mp, 3.

Family RUTACEAE

Citrus sp., Mp, 5 (N, A), 25, 59 (N, A).
Zanthoxylum americanum Miller, As, 9, 36, 48 (N), 49; Mp, 9, 49.

Family ACERACEAE

Acer negundo Linnaeus, Mp, 14, 49.
Acer saccharinum Linnaeus, Mp, 62 (A).
Acer sp., Ab, 23; As, 23; Mp, 37 (N), 38, 45, 49.

Family BALSAMINACEAE

Impatiens balsamina Linnaeus, Ab, 40, 49.

Family AQUIFOLIACEAE

Ilex sp., Mp, 25.

Family CELASTRACEAE

Celastrus scandens Linnaeus, As, 9, 36, 48 (N), 49.

Family BUXACEAE

Buxus sp., As, 25, 47.

Family VITACEAE

Ampelopsis sp., As, 47.
Vitis sp., Ac, 3, 7, 9; As, 4, 9, 23, 36, 47, 48 (N), 49, 63; Mp, 3, 9, 36, 43, 49, 56, 63; Ov, 9.

Family TILIACEAE

Tilia sp., Ac, 18, 49; Mp, 9, 25, 49, 53.

Family MALVACEAE

Gossypium hirsutum Linnaeus, Ac, 7, 9, 12, 15; Mp, 1.
Hibiscus cannabinus Linnaeus, Mp, 5 (N).

Family VIOLACEAE

Viola sp., As, 47.

Family PASSIFLORACEAE

Carica papaya Linnaeus, Mp, 5 (N).

Family TAMARICACEAE

Tamarix articulata Vahl, Mp, 5 (N).

Family LYTHRACEAE

Punica granatum Linnaeus, Mp, 5 (N).

Family MYRTACEAE

Psidium guajava Linnaeus, Mp, 5 (N).

Family ONAGRACEAE

Oenothera biennis Linnaeus, Mp, 6.

Family CORNACEAE

Cornus drummondi Meyer, As, 48 (N).
Cornus florida Linnaeus, As, 62 (A).
Cornus sp., Ac, 23; As, 9, 36, 48 (N), 49; Mp, 23.

Family ARALIACEAE

Panax quinquefolium Linnaeus, Ac, 21; Mp, 21.

Family ERICACEAE

Kalmia sp., Mp, 25.
Rhododendron sp., Mp, 25.
Vaccinium corymbosum Linnaeus, Ab, 39, 51.
Vaccinium macrocarpon Aiton, Ab, 36, 39, 40 (N, A), 41, 42, 49.
Vaccinium sp., As, 51.

Family OLEACEAE

Jasminum grandiflorum Linnaeus, Mp, 5 (N).
Ligustrum amurense Carriere, Mp, 60 (N).
Ligustrum vulgare Linnaeus, Mp, 9, 11, 25, 38.
Ligustrum sp., Mp, 49, 56.
Fraxinus berlanderiana A. DeCandolle, Mp, 5.
Fraxinus sp., Ab, 23; As, 23; Mp, 9, 25, 49, 53.
Syringa vulgaris Linnaeus, Ac, 3, 7, 9, 32, 36, 49.

Family APOCYNACEAE

Allamanda cathartica Schrader, Mp, 5 (N).

Family ASCLEPIADACEAE

Asclepias sp., Ac, 7, 9, 49.

Family CONVOLVULACEAE

Ipomoea sp. , Ab, 23.

Family BORAGINACEAE

Ehretia anaqua (Johnson), Mp, 5.

Family LABIATAE

Nepeta cataria Linnaeus, Ac, 7, 9, 49.
Salvia sp., Mp, 57 (N, A).

Family SOLANACEAE

Solanum rostratum Dunal, Ac, 7.
Solanum tuberosum Linnaeus, Mp, 3.
Solanum sp., Mp, 5 (N).

Family BIGNONIACEAE

Anistostichus capreolata (Linnaeus), As, 9.
Campsis radicans (Linnaeus), Mp, 3.
Catalpa sp., Mp, 10.

Family CAPRIFOLIACEAE

Viburnum sp., Mp, 25.
Weigelia florida (Siebold and Zuccarini), As, 47.

Family COMPOSITAE

Ambrosia sp., Ab, 23; Ac, 7, 9, 36, 49.
Dahlia sp., Mp, 3, 30, 32, 57.
Erigeron canadensis Linnaeus, Mp, 37 (N), 45.
Galinsoga sp., As, 47.
Rudbeckia hirta Linnaeus, Ab, 23.
Solidago sp., Ab, 23, 36, 40, 48 (N), 49; Ac, 23.
Verbesina sp., As, 62.

[a]Ab = *A. bivittata,* Ac = *A. conica.* As = A., septentrionalis, Mp = *pruinosa,* Ov = *O. venusta.*
[b]N = nymph, A = adult. Most authors did not state whether the planthoppers observed and/or collected were nymphs or adults. However, we assume that most records are of adults since nymphs cannot be easily identified.

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SWEET-STALKED CORN

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ABSTRACT

More than two decades ago, hybrids of sweet-stalked (SS) corn were proposed as high-value feed silage. Because of their high sugar contents, they now assume new importance as crops for energy or as multi-purpose crops for both feed and energy. Existing unpublished data from a 2-year study reveal that stalk yields of SS hybrids and a check hybrid were similar at harvest; but during silage stage (September), stalk sugar contents (30 and 34%) of the SS hybrids were 1.2 to 1.6 times those found for the check hybrids. Data for materials obtained after a heavy frost showed that, while sugar contents declined for all hybrids, the SS hybrids had sugar contents of 2 to 3-½ times those of the check hybrids (6-7%). The SS hybrids merit further study to evaluate more fully their potential not only to produce grain but also to produce fermentable sugar and cellulose.

INTRODUCTION

The presence of sugar in cornstalks has long been known. Stalks of corn provided sugar to the Aztecs even before the Spanish Conquest of Mexico (Singleton, 1948). Since corn can produce and store large quantities of sugar in the stalk, silage of high value may be produced from hybrids of high-sugar inbreds (Jugenheimer, 1976; Singleton, 1948). Blanco *et al.* (1957), in Spain, and Jugenheimer and Williams (1959), working with selected Spanish hybrids in Illinois, experimented extensively to develop corn for dual purposes, grain and stover (cured stalks used as fodder); at maturity, the stalks still contain high quantities of sugar. More than twenty years ago, we initiated a study to evaluate sweet-stalked (SS) corn as a possible multi-purpose crop for the United States. The grain and stover yields were determined, and the stalk was examined as a possible sucrose source or a high-energy silage or fodder. With current interest in biomass resources and multi-purpose crops (Buchanan and Otey, 1979), those data assume greater status. Consequently, we reevaluated these previously unreported data in terms of current interests.

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*The mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned.

MATERIALS AND METHODS

During the first year, seven Spanish hybrids of SS corn and one hybrid common to the Corn Belt were grown at the University of Illinois. Replicated plantings were harvested at three intervals; before frost (silage stage), after a light frost, and after a heavy frost. Of samples containing 40 stalks, five or six stalks were randomly selected, sectioned, and frozen. Leaves from the last two harvests and ears from the first harvest were discarded. All samples were freeze-dried and then ground in a Wiley mill to pass a 1-mm screen. Samples were analyzed for reducing and total sugar contents and nitrogen.

In the second year, four SS hybrids and one Corn Belt hybrid were grown as before. These hybrids were harvested in triplicate at two dates; before frost and after a heavy frost. From each sample, six to eight stalks were separated into ear, shuck and shank, leaf, and culm components. The culms were sectioned and frozen as were the leaves, shucks, and shanks. After being freeze-dried and ground in a Wiley mill to pass a 1-mm screen, all samples were analyzed for total sugar content and nitrogen.

Sugars were extracted and hydrolyzed by a modification of the official methods for reducing sugar and sucrose (Association of Official Agricultural Chemists, 1955). The Micro Method for reducing sugars was used to analyze for sugar content of all samples. Nitrogen was determined by the Kjeldahl method and calculated as crude protein. Yields of forage and grain were calculated on the basis of assuming 15,000 plants per acre and one ear per plant.

RESULTS AND DISCUSSION

Sugar contents in culms of seven SS corn hybrids were higher than those in the culms of a Corn Belt hybrid check (Table 1). Reducing and total soluble sugars of the SS hybrids exceeded those of the check at both the silage and post-frost stages. Reducing sugar, representing about 50% of the total sugar, decreased somewhat less between harvest intervals than did sucrose. Such a high percentage of reducing sugar would seem to render impratical the use of the stalks as a source of crystalline disaccharide. However, this would be of no concern if the sugar remains as an added energy source in a silage or fodder. Lack of crystallinity would likewise be inconsequential in serving as a fermentation substrate. The total sugar contents in the stalks of the SS hybrids exceeded those of the control 1-½ times at the silage stage and increased that difference to 3-½ times after a heavy frost.

In the second year of the study, total soluble sugars present in all components of the stalks were determined at silage and post-frost harvest stages (Table 2). With the possible exception of the leaf fraction from the post-frost harvest, the four SS hybrids contained more sugar in all components than did the Corn Belt hybrid at the respective harvest stages.

Nathan (1978) reported on the evaluation of sugar crop grasses, e.g., sugarcane and sweet sorghum, as raw materials for producing fuel and chemical feedstocks. Sugarcane was considered most promising, with sweet sorghum becoming more promising in the future after more developmental work.

An examination of a report by Lipinsky *et al.* (1979) reveals that maximum total sugars in stalks, at experimental sites in 1978, from sugarcane (3 locations) and sweet sorghum (5 locations) were 34-52% and 29-34%, respectively. In the two-year study of SS corn, total sugars in the culms at silage stage were 28-40%. Although the SS corn did not contain as much total sugar as reported for some sugarcane, its range of values overlapped that of sweet sorghum and part of the range of values for sugarcane.

To select varieties for multiple use or for biomass to produce alcohol, using stalks as well as grain, the chemist, microbiologist, and plant scientist would be interested in total yields per acre. The limited data acquired in this study indicate that forage yields of SS and Corn Belt hybrids are similar (Table 3). However, in the important criterion of grain production, these limited data indicate that the control hybrid is more productive. These data are consistent with yield data reported by

Table 1. Sugar in Cornstalk Culms* (Oven Dry)

Identification	Silage stage sugar, Reducing, %	Silage stage sugar, Total, %	Post-frost harvest sugar, Reducing, %	Post-frost harvest sugar, Total, %
Sweet-stalked, P.I. no.				
240056	19.1	40.4	9.4	17.6
240057	16.2	33.9	6.8	14.8
240058	15.4	28.0	10.7	20.1
240066	14.8	35.0	13.2	26.2
240067	17.2	35.8	14.0	26.6
240070	19.0	34.1	15.1	26.4
240071	16.6	32.8	11.9	19.6
Check, Ill. no.				
1570	12.0	21.2	4.5	6.0

*First year experiment.

Table 2. Sugar in Corn Plants* (Oven Dry)

	Sugar, total %					
	Silage stage			Post-frost harvet		
Identification	Leaf	Shuck and shank	Culm	Leaf	Shuck and shank	Culm
Sweet-stalked, P.I. no.						
240057	5.5	23.1	28.9	0.8	3.3	15.9
240058	5.7	25.3	28.2	3.0	3.2	13.7
240066	4.7	24.4	32.0	2.3	2.7	10.7
240070	6.2	21.5	30.8	0.6	3.0	10.8
Check, Ill. no.						
1570	4.0	20.5	25.8	1.8	1.9	7.0

*Second year experiment.

Jugenheimer and Williams (1959). By contrast, Blanco *et al.* (1957) found that their group of experimental SS hybrids yielded more grain than did a group of standard American hybrids.

Since corn silage is deficient in protein, an evaluation of new varieties of corn for silage should emphasize their protein content. The corn plants of SS and control hybrids analyzed in this study were similar in protein content (Table 4). Based on protein content, the leaf appears to be the most nutritive part of the plant, but it stores little of the sugar. Consequently, it should be technically feasible to divert the leaf for feed and leave most of the carbohydrates for fermentation.

Lipinsky (1978) suggested a change of the usage of the corn biomass system in the United States. His proposal would permit production of 10-18 billion liters of ethanol from the grain while maintaining the same quantity of food in the form of beef, poultry, and pork. After ethanol production, the protein rich stillage from some of the grain would be fed to ruminants. An amount of corn stover equivalent to grain used for ethanol would be harvested and fed with the stillage to the cattle. The quantity of grain fed to nonruminant animals (poultry and hogs) and grain converted into starch and other byproducts would not change. That concept should allow removal of most soluble sugars from SS hybrids without adverse effect on feed value when compared to traditional hybrids.

Table 3. Corn Crop Production of Experimental Hybrids

	Yields*		
	Forage		Grain
Hybrids	Silage stage lbs/a (d.b.)	Post-frost harvest lbs/a (d.b.)	bu/a
Sweet-stalked	5850	3380	95
Check, Ill. 1570	5380	3160	114

*Calculated on basis of assuming 15,000 plants per acre and one ear of corn per plant.

Table 4. Protein in Corn Plants (Oven Dry)

	Protein, %			
	Silage Stage		Post-frost Harvest	
Identification	leaf	Culm	Culm	Grain
Sweet-stalked	14.2	3.2	3.5	10.8
Check, Ill. 1570	13.0	3.5	3.5	9.4

The residue from the most important crop of American agriculture, corn, can provide domestically renewable products for liquid fuel. With high content of polysaccharides, cornstalks are of special interest for conversion to sugars for alcohol or chemical feedstock production. In selection of corn hybrids, high sugar contents demonstrated by the SS hybrids would be beneficial as a feedstock for alcohol or feed for animals. More sugar in the stalks makes the plants even more desirable for alcohol fuel production. Even after a heavy frost, the 13-22% sugar in the SS hybrids compared to the 6-7% in the control makes these stalks more valuable as feedstock for ethanol production.

Further work with SS corn should enhance yields of grain as well as forage with favorable carbohydrate contents. The wealth of information about corn and the quantity of fermentable sugars produced and maintained by SS corn could be used to develop a mult-purpose crop system. Both basic and applied research studies need to be initiated to further improve the desirable characteristics of SS corn and to develop its agronomic, harvesting, handling, and storage technology.

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SOME ASPECTS OF THE ALIEN COMPONENT OF THE SPONTANEOUS ILLINOIS VASCULAR FLORA

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ABSTRACT

Comparative studies of twelve Illinois vascular plant floras published between 1846 and 1978 indicate that there has been an increasing number of alien species in the spontaneous vascular flora and that they now constitute about 29% of the flora. Of these alien species, 77% have Old World origins, 54% are escaped cultivated species, 81% are considered weeds somewhere in the United States, and 13% are woody species. Most of the Illinois aliens occur primarily in disturbed areas with far fewer in undisturbed areas. In comparison with other states and regions in the United States, Illinois has a rather high percent of alien species in the spontaneous flora.

INTRODUCTION

Many aspects of the Illinois vascular plant flora have been examined, resulting in a rather complete and current knowledge of most of these aspects. The floristic and systematic aspects have been documented by Mohlenbrock (1975), Mohlenbrock and Ladd (1978), Mohlenbrock (1967, 1970a, 1970b, 1972, 1973, 1976, 1978, 1980), Myers (1972), Jones and Fuller (1955), and Winterringer and Evers (1960); the vegetational aspect by Jones (1963), Jones and Fuller (1955), Anderson (1970), and Schwegman (1973); the preservation and protection aspect by White and Corbin (1978), Illinois Department of Conservation (1979) and in addition, a list of endangered and threatened vascular plant species has been submitted to the Illinois Endangered Species Protection Board for official approval; and the recreational aspect by the Illinois Department of Conservation (1978).

With all of this knowledge of the Illinois vascular flora, analysis of the alien component has generally been neglected. With the exception of Myers (1972), the last account of the alien flora of Illinois was published nearly 60 years ago by Darlington (1922), who listed and discussed the herbaceous introduced flora from 1826 to 1921. Darlington did not include tree and shrub introductions as he did not consider them to be weeds. His paper was written from the standpoint of introduced plants being actual or potential weeds in Illinois. The study which follows represents an attempt to summarize and update certain aspects of the alien component of the spontaneous Illinois vascular flora.

METHODS

The present spontaneous vascular plant flora of Illinois was taken to be those plants listed in Mohlenbrock and Ladd (1978). Assignment of species to alien status was based on information in Fernald (1950), Gleason (1953), Jones (1945, 1950, 1963), Jones and Fuller (1955), Mohlenbrock (1975), Myers (1972), and Shetler and Skog (1978). Twelve Floras have listed the vascular plants of Illinois, the first being in 1846 and the most recent in 1978 (Table 1). For each of the twelve floras the percentage of spontaneously-occurring alien plant species was determined using information provided in the floras as well as the species determined to be alien as stated above. All nomenclature was standardized to Mohlenbrock and Ladd (1978). Hybrids and infraspecific taxa were not used except when a subspecific taxon was the only one for a species in the flora.

The geographical origin of the aliens was determined by consulting Fernald (1950), Jones (1963), Mohlenbrock (1975), Myers (1972), and Bailey (1949). Aliens were evaluated as to their weed status in the United States from Darrow (1966) and in Illinois from Slife, Buchholtz and Kommedahl (1960) and Illinois Department of Agriculture (1978). Bailey (1949), Mohlenbrock (1975) and Myers (1972) were examined to determine which aliens have been cultivated.

RESULTS AND DISCUSSION

Percent of Aliens in the Flora. The percent of alien species in the spontaneous Illinois flora has risen from 10.2% in 1846 to 28.7% in 1978 (Table 1) confirming the steady increase of alien flora constituents over the past 132 years.

The unexpectedly high proportion of alien species in 1846 may be due to Dr. Mead's interpretation of the status of plants having "been introduced and occasionally seen growing spontaneously about gardens and cabins" being too liberal.

The increase in the number of alien species from the time of settlement to the present undoubtedly reflects the parallel increase in man's activities in the state, including agriculture, urbanization, industrialization, recreation and transportation. There has been a general increase of alien species introduced per year into the flora up to the present: 2.18 between 1846 and 1878, 2.63 between 1879 and 1945, and 14.4 between 1946 and 1978. According to Darlington (1922) between 1826 and 1921 the largest herbaceous alien increase per year was 3.3 between 1872 and 1897 which he explained was due to a "rapid settling of farm lands." The high rate of introduction per year of woody and herbaceous aliens since World War II (which is more than four times that between 1872 and 1897) probably is due to the increase of disturbed land accompanying the very intense agricultural-urban-industrial development associated with the increase in population. Apparently the first collector of plants in Illinois was the French botanist Michaux (Mohlenbrock, 1975) who collected 89 plants of which three (3.4%) were aliens: *Polygonum aviculare, Polygonum hydropiper* and *Cardiospermum halicacabum.* Darlington (1922) omitted the latter two species from his list.

Alien plants form a higher percent of the present floristic additions in relation to native plant species which formed more of the additions to past floras. Between 1964 and 1978, 59% of all new species in the flora were aliens, whereas from 1975 to 1978 aliens were 75.3% of the additions. The additional taxa discovered too late to be incorporated into the text of Mohlenbrock (1975) and Mohlenbrock and Ladd (1978) were 70.8% and 86.6% alien plants respectively.

Origins of Aliens. The majority (77%) of the aliens in the present flora originated in the Old World. Nineteen percent originated from the continental United States outside of Illinois (14% from west of the Mississippi River) with the remaining Illinois aliens originating in the New World Tropics. For Illinois aliens originating elsewhere in the United States, the breakdown of origins by U.S. geographic area is as follows: N, 0%; NE, 2%; E, 7%; SE, 10%; S, 9%; SW, 13%; W, 62%; and NW, 1%. Clearly, most plants that are not native to Illinois but have origins in the United States come from the West and Southwestern parts of the country.

It is interesting to note that the sources of aliens in the flora are nearly identical to those reported by Darlington in 1922, who found 78% of aliens having an Old World Origin, 14% from the United States west of the Mississippi, and 6% from the New World Tropics.

Aliens Introduced Through Cultivaion. A major source of aliens in the present flora is the introduction of plants for cultivation. Many of these plants escape from cultivation and occur spontaneously. Fifty-four percent of the alien species determined to be occurring spontaneously in Illinois are, or have at some time, been cultivated.

There is a trend for deliberately introduced cultivated aliens to escape and form a higher amount of the present alien flora in relation to the accidentally introduced weedy type aliens which comprised more of the earlier aliens introduced into the flora. The additional alien taxa discovered too late to be incorporated into the text of Mohlenbrock (1975) and Mohlenbrock and Ladd (1978) were 58.8% and 61.5% escaped cultivated plants respectively. Myers (1972) states that of all 150 species reported between 1963 and 1972, over half were alien cultivated plants. From 1964 to 1978, 40.9% of the added alien herbaceous plants and 100% of the added alien woody plants

TABLE 1

Percent of Alien Species in the Illinois
Spontaneous Vascular Plant Flora from 1846 to 1978

Flora Author	Year of Publication	% Alien Species
Mead	1846	10.2
Lapham	1857	6.6
Patterson	1876	7.5
Flagg & Burrill	1878	10.5
Jones	1945	15.9
Jones	1950	15.9
Jones & Fuller	1955	25.0
Winterringer & Evers	1960	26.0
Jones	1963	24.7
Myers	1972	25.4
Mohlenbrock	1975	27.9
Mohlenbrock & Ladd	1978	28.7

TABLE 2

Percent of Alien Species in Other States
or Regions of the United States

State or Region	Source	Year	% Alien Species in the Flora
Northeastern U.S.	Gleason, 1963	1890	12.7
Northeastern U.S.	Robinson & Fernald, 1908	1908	16.3
Northeastern U.S.	Fernald, 1950	1950	19.8
New England	Seymour, 1969	1969	30.5
Arizona	Kearney & Peebles, 1964	1964	7
Indiana	Myers, 1972	1940	15
Missouri	Steyermark, 1963	1963	23
Vermont	Dole, 1937	1937	24
S.E. Washington and Adjacent Idaho	St. John, 1963	1963	14

were escaped cultivated plants. Of all the woody aliens in the flora today, 99% are escaped cultivated species. By 1972, 58% of the 351 naturalized aliens had been cultivated as ornamentals or introduced for economic purposes (Myers, 1972).

Weed Component of Alien Flora. The alien flora of Illinois was examined to determine how many alien species were considered weedy. Based on Darrow (1966), it was ascertained that 81% of the alien plants in this state are weeds at least somewhere in the United States. Twenty percent of plant species alien to Illinois are weeds in Illinois based on Slife, Buchholz, and Kommedahl (1960). These figures are in contrast to the native Illinois flora, 25% of which are weeds somewhere in the U.S. and 4.5% of which are considered to be weeds in Illinois. Of the legislated Illinois noxious weeds (Illinois Department of Agriculture, 1978), six of the eight plants listed are aliens. Myers (1972) reported that over 200 (8.7%) of the 2281 established plants (native and naturalized aliens in the Illinois flora were weeds.

Habitats of Aliens. The 758 alien species reported for the state as of 1975 were categorized as to their typical habitat according to Mohlenbrock (1975). As might be anticipated, most (54%) of the aliens occurred in disturbed and waste ground habitats. Another 3% had a wet habitat and 2% were found in woods or prairie. Forty-one percent of the aliens listed did not have information concerning habitat; however, it seems reasonable to assume that many of these would also occur in disturbed environments.

Much of the land area in Illinois has suffered at least some disturbance as evidenced by figures from the Illinois Cooperative Extension Service (1975) which reports 72% of the land area in Illinois is used for agricultural crops, 19% is in woods, pasture and grasslands plus aquatic areas, wetlands and other land having low value for agricultural purposes, and the remaining 9% of land area is urbanized. Today relatively undisturbed areas include less than 0.1% of the total land and water areas of Illinois (White and Corbin, 1978).

Certain Illinois counties were selected to determine if it is possible to correlate the amount of disturbance in a county with the percent of alien species in the flora of that county. For each county selected, the percent of alien species was determined from the total number of plants reported for that county, using Mohlenbrock and Ladd (1978). Cook County, a highly urbanized and populous county which includes Chicago, has a flora composed of 38% alien species, reflecting the extensive land disturbance. Likewise, Livingston County, with almost total land disturbance due to intensive agriculture, has an alien species component of 28%. By contrast, two of Illinois' least ecologically disturbed counties, Pope and Hardin, had alien species totals of 16% and 15% respectively.

Woody Aliens. Woody species, primarily trees and shrubs, comprise 13% of the present alien flora. Woody vines represent only about one-tenth of all woody alien species.

Darlington (1922) states that he excluded shrub and tree introductions (such as *Populus alba, Salix alba,* etc.) "since they are hardly to be counted as weeds." Nevertheless, he did include two woody shrub aliens (*Rosa rubiginusa*[5][R. eglanterial] and *Lycium holimifolium)* in his list. That woody plants can be weeds is substantiated by the fact that 35.3% of the woody alien species in the Illinois vascular flora are on the list of plants (Darrow, 1966) considered weeds in the United States. Today, a number of alien woody plants can be considered weeds in Illinois, e.g. *Rosa multiflora, Lonicera japonica, Ailanthus altissima, Maclura pomifera, Morus alba,* and *Populus alba.* Considering the time, effort and money spent to eradicate "brush", many woody plants both native and alien can certainly be categorized as weeds.

Percent of Aliens in Other States. Current information about the number of aliens in other states is not always available, but a search of some state and regional floras yielded some data with which to compare Illinois' alien flora (Table 2). Illinois, with nearly 29% alien species in its flora, appears to have a relatively high alien composition. More recent information for other states particularly in the East will probably find higher numbers of alien species. There seems to be a trend toward fewer alien species as one travels westward in the United States.

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LIVERWORTS AND HORNWORTS OF FERNE CLYFFE STATE PARK, JOHNSON COUNTY, ILLINOIS

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ABSTRACT

Ferne Clyffe State Park, with habitats ranging from xeric blufftops to lowland woods, possesses an anthocerote and hepatic flora of 40 taxa. Thirty-five of these are reported for the first time from the park and 26 are reported for the first time from Johnson County, Illinois. No taxa new to Illinois were found. The earlier report of *Scapania undulata* (L.) Dum. and *Plagiochila undata* Sull. was based on misidentified specimens.

INTRODUCTION

Ferne Clyffe State Park is located in Goreville Township of northwestern Johnson County (sections 22, 27, 28 and 33 of T11s, R2E). The 412 hectares within the park lie in the Greater Shawnee Hills Section of the Shawnee Hills Division, just north of the Lesser Shawnee Hills Section. This Division is unglaciated with east-west sandstone encarpments, faulted bedrock formations and rocky, cascading streams (Reuter, 1977). The exposed bedrock dates from the Mississippian and Pennsylvanian Periods of the Paleozoic Era and contains three basic rock formations: The Kinkaid Formation consisting of Kinkaid Limestone, the Caseyville Formation consisting of Lusk Sandstone, Battery Rock Sandstone, Drury Shale and Pounds Sandstone and the Abbott Formation consisting of Grindstaff Sandstone. Pounds Sandstone is the most dominant outcrop feature of the park whereas Battery Rock Sandstone and Drury Shale are of slightly less occurrence. The Battery Rock Sandstone is characterized by a conglomerate of well-rounded pebbles of chert, quartzite and vein quartz, all of which reach a maximum diameter of 12.7 mm while Pounds Sandstone, although similar, contains smaller quartz pebbles. The Drury Shale member is composed of thinly-bedded gray shales with lenses of medium grained sandstone (Reuter, 1977).

Elevation in the park varies from 122 m above sea level in the valleys to over 201 m above sea level on the blufftops. Numerous wooded slopes, blufftops, and vertical sandstone of various aspects, lowland woods, old fields and a man-made lake allow for a diversity of vascular plants which includes over 700 taxa, 22 of which are ferns or fern allies (Mohlenbrock *et al.*, 1966). The area consists of mainly of an oak-hickory forest dominated by *Quercus stellata* Wang., *Quercus marilandica* Muench., *Ulmus alata* Michx. and *Juniperis virginiana* L. on the blufftops, *Quercus alba* L., *Carya tomentosa* (Poir.) Nutt., *Carya ovata* (Mill.) K. Koch and *Juniperus virginiana* on the slopes; *Ulmus americana* L., *Acer saccharum* Marsh., *Liriodendron tulipifera* L., *Quercus rubra* L. and *Quercus alba* in the lowlands.

Although collecting was done in all parts of the park, three areas were sampled extensively, namely, Happy Hollow, Black Jack Oak Trail and Round Bluff. Happy Hollow is a narrow northeast to southwest valley, which contains a small stream and many sandstone slump blocks, bounded by high sandstone bluffs on both sides. Because of small canyons with intermittent waterfalls leading off the major valley, there are vertical sandstone walls of varying aspects and hence numerous microhabitats. Black Jack Oak Trail is a south, southwest to west facing blufftop area and is part of a line of bluffs which run through the park from northwest to southeast for a distance of nearly five kilometers (Mohlenbrock *et al.*, 1966). Not only were the xeric blufftops sampled but also the more

mesic base of the cliffs. Round Bluff, a 21.5 hectare location designated as an Illinois Nature Preserve, consists of vertical sandstone cliffs with exposures in all directions. The diverse aspects and natural spring and seepage areas allow for a multitude of microhabitats ranging from shaded and moist to exposed and dry conditions.

Personal collections made were deposited in the university herbarium (SIU) with duplicates when available in ABSH. Other collections examined included those of G.N. Jones (ILL), R.E. Hatcher, A.C. Skorepa and K.A. West (SIU) as well as specimens from the private herbaria of P.L. Redfearn, Jr. and R.E. Stotler.

RESULTS AND DISCUSSION

The numerous habitats found throughout Ferne Clyffe State Park allow for a rather large assemblage of liverworts and hornworts. The relatively undisturbed xeric blufftops possess a rich thalloid liverwort flora, comprising four species of *Riccia* L. and *Asterella tenella* (L.) P. Beauv. as well as the simple thalloid *Fossombronia foveolata* Lindb. Numerous vertical sandstone cliffs of varying aspects also provide variable microhabitats which inhabited by a fairly substantial number of both leafy and thalloid liverworts. Not only do the common species such as *Conocephalum conicum* (L.) Lindb., *Scapania nemorosa* (L.) Dum., *Plagiochila porelloides* (Torrey ex Nees) Lindenb., *Calypogeja muelleriana* (Schiffn.) K. Mull., *Radula obconica* Sull. and *Lophocolea heterophylla* (Schrad.) Dum. occur in these habitats but also the rarer *Jungermannia fossombronioides* Aust., *Lophocolea cuspidata* (Nees) Limpr., *Lejeunea lamacerina* (Steph.))Schiffn. subsp. *gemminata* Schust. and *Pallavicinia lyellii* (Hook.) Carruth.

Thirty-five of the 40 taxa are reported for Ferne Clyffe for the first time. No liverworts or hornworts new to Illinois were found, but 26 taxa new to Johnson County are reported. *Scapania undulata* (L.) Dum. and *Plagiochila undata* Sull. which had been reported from this park (Skorepa, 1968) were misidentifications of *Scapania nemorosa* (L.) Dum. and *Plagiochila porelloides* (Torrey ex Nees) Lindenb., respectively. The nomenclature used, follows that of Stotler and Crandall-Stotler (1977).

Checklist of Taxa in Ferne Clyffe State Park,
Arranged Alphabetically

Division Anthocerotophyta (Hornworts)

1. *Notothylas orbicularis* (Schwein.) Sull. - Rare on moist soil in lowland woods; *Zehr 1383.*
2. *Phaeoceros laevis* (L.) Prosk. - Uncommon on moist soil and moist sandstone; *Redfearn 18107; Zehr 1372, 1392, 1409.*

Division Hepatophyta (Liverworts)

3. *Asterella tenella* (L.) P. Beauv. -Common on soil on blufftop ridges; *Zehr 1363, 1599, 1600, 1601.*
4. *Calypogeja muelleriana* (Schiffn.) K. Mull. - Very common on moist soil and sandstone covered by thin soil; *Zehr 1189, 1132, 1411, 1185, 1248, 1387, 1393, 1411, 1403, 1562, 1590, 1591, 1703, 1704, 1708, 1710.*
5. *Calypogeja trichomonis* (L.) Corda - Rare on soil near moist sandstone; *Zehr 1241, 1382, 1554.*
6. *Cephaloziella divaricata* (Sm.) Schiffn. - Rare on blufftops; *Zehr 1636, 1670.*
7. *Cephaloziella hampeana* (Nees) Schiffn. - Uncommon but locally abundant on moist soil along path by lake; *Zehr 1669, 1671, 1672.*
8. *Cololejeunea biddlecomiae* (Aust.) Evans - Common on vertical sandstone, moist rocks along stream and rotting logs; *Zehr 1364, 1368, 1369.*
9. *Conocephalum conicum* (L.) Lindb. - Common on moist sandstone and moist soil under rock overhangs; *Zehr 1244.*
10. *Diplophyllum apiculatum* (Evans) Steph. - Occasional on moist sandstone; *Redfearn 18060; Zehr 1555, 1564, 1711.*

11. *Fossombronia foveolata* Lindb. - Common on dry exposed blufftops; *Zehr 1391.*
12. *Frullania eboracensis* Gott. On *Juniperus* bark; *Zehr 1184, 1729.*
13. *Frullania ericoides* (Nees) Mont. - Rare on *Juniperus* bark; *Jones 20114.*
14. *Frullania inflata* Gott. - Very common on dry exposed sandstone and the bark of various tree species; *Zehr 1125, 1161, 1169, 1188, 1379, 1396, 1402, 1381, 1596, 1597, 1598, 1604, 1732.*
15. *Jamesoniella autumnalis* (DC.) Steph. - Uncommon on moderately moist sandstone and *Juniperus* logs; *Redfearn 18105; Zehr 1726, 1730, 1731.*
16. *Jubula pennsylvanica* (Steph.) Evans - Rare on moist shaded sandstone; *Zehr 1561, 1565* p.p., *1679, 1709.*
17. *Jungermannia crenuliformis* Aust. - Fairly common on moist sandstone; *Zehr 1683, 1395; Stotler 1168; Redfearn 18101, 18089.*
18. *Jungermannia fossombronioides* Aust. - Rare on moist sandstone; *Zehr 1371.*
19. *Jungermannia hyalina* Lyell - Rare on moist sandstone; *Zehr 1395.*
20. *Lejeunea lamacerina* (Steph.) Schiffn. subsp. *gemminata* Schusts. - Rare on moist sandstone, mixed with *Radula obconica; Zehr 1715.*
21. *Leucolejeunea clypeata* (Schwein.) Evans- Common on fairly dry sandstone; *Redfearn 18068; Zehr 1407, 1413, 1586, 1633, 1707, 1699, 1712, 1718.*
22. *Lophocolea cuspidata* (Nees) Limpr. - Rare on moist sandstone, occurring with *Jubula pennsylvanica; Zehr 1565.*
23. *Lophocolea heterophylla (*Schrad.) Dum.- Very common on soil, sandstone, rotting logs and at the base of various tree species; *Zehr 1374, 1373, 1378, 1377, 1385, 1394, 1380, 1557, 1587, 1594, 1667, 1376, 1695.*
24. *Lophocolea minor* Nees - Common on moist sandstone and rotting logs; *Zehr 1240, 1251, 1375, 1558, 1559, 1632, 1700.*
25. *Metzgeria conjugata* Lindb. - Rare on moist shaded sandstone; *Zehr 1561 p.p.* with *Jubula pennsylvanica.*
26. *Odontoschisma prostratum* (Sw.) Trev. - Common on moist north-facing sandstone; *Zehr 1164, 1244, 1247, 1252, 1365, 1556, 1563, 1634, 1639.*
27. *Pallavicinia lyellii* (Hook.) Carruth. - Rare on moist sandstone; *West s.n.; Zehr 1696.*
28. *Pellia epiphylla* (L.) Corda - Fairly common on moist sandstone; *Hatcher 1163; Zehr 1258, 1260, 1538, 1665.*
29. *Plagiochila porelloides* (Torrey ex Nees) Lindenb. - Very common on moist sandstone; *Hatcher 1164; Stotler 1169; Redfearn 18053; Zehr 1221, 1412, 1414, 1405, 1408, 1631, 1716, 1717, 1719.*
30. *Porella pinnata* L. - Common on sandstone and tree bases; *Zehr 1168, 1181, 1401, 1406, 1415, 1592, 1630, 1593.*
31. *Porella platyphylloidea* (Schwein.) Lindb. - Common on sandstone and the bark of various tree species; *Redfearn 18096; Zehr 1165, 1606.*
32. *Radula obconica* Sull. - Common on moist sandstone and occasionally on trees; *Zehr 1588, 1404, 1706, 1713, 1714, 1715, 1705, 1694, 1698, 1715 p.p.* with *Lejeunea lamacerina.*
33. *Reboulia hemisphaerica* (L.) Raddi - Common on moderately moist to dry sandstone and soil; *Skorepa 3881; Stotler 1166; Zehr 1198, 1201, 1242, 1249, 1259, 1370, 1612.*
34. *Riccia austini* Steph. - Fairly common on soil on exposed blufftops; *Zehr 1204, 1662.*
35. *Riccia beyrichiana* Hampe ex Lehm. - Fairly common on soil on exposed blufftops; *Zehr 1723, 1724.*
36. *Riccia dictyospora* M.A. Howe - Fairly common on soil on exposed blufftops; *Zehr 1106, 1107, 1199, 1661, 1663.*
37. *Riccia fluitans* L. - Of rare occurrence on moist clay soil in lowland woods; *Zehr 1388.*
38. *Riccia hirta* (Aust.) Underw. - Very common on soil on exposed blufftops; *Zehr 1200, 1389, 1660, 1664, 1668.*

39. *Riccia membranacea* Gott. et Lindenb. - Rare on moist clay soil in lowland woods, occurring with *Riccia fluitans* and *Notothylas orbicularis; Zehr 1390.*
40. *Scapania nemorosa* (L.) Dum. - Very common on moist sandstone and soil; *Redfearn 18066, 18086, 18092; Zehr 1666, 1560, 1117, 1116, 1130, 1121, 1128, 1250, 1253, 1255, 1254, 1400, 1399, 1398, 1397, 1366, 1386, 1384, 1367.*

SUMMARY

A fine assemblage of blufftop liverworts occur throughout the park. Not only are the more common *Asterella tenella* (L.) P. Beauv. and *Fossombronia foveolata* Lindb. represented but also numerous species of *Riccia* L. Plants of rarer occurrence in this area of the country but which were found in the numerous microhabitats of Ferne Clyffe include *Lophocolea cuspidata* (Nees) Limpr., *Lejeunia lamacerina* (Steph.) Schiffn. subsp. *gemminata* Schust., *Frullania ericoides* (Nees) Mont., *Notothylas orbicularis* (Schwein.) Sull., *Pallavicinia lyellii* (Hook.) Carruth. and *Jungermannia fossombronioides* Aust. The 40 taxa of liverworts and two taxa of hornworts occurring in this area provides a diverse flora of slightly less than the 48 taxa reported for Lusk Creek Canyon Nature Preserve, Pope County, by Crandall-Stotler and Stotler (1978) but more than the 32 species from Little Grand Canyon, Jackson County (Stotler, 1976), and the 21 species from Panther's Den, Union County, by west and Stotler (1977).

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Population Stability in the Gizzard Shad Population of Crab Orchard Lake, Illinois

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Abstract

A 25 year reanalysis of the gizzard shad, *Dorosoma cepedianum* (Le Sueur), population in Crab Orchard Lake, Illinois, was conducted for the purposes for comparison. The gizzard shad population has remained relatively stable in regard to age composition, however, the condition of the fish has dramatically declined. Coefficient of condition appears highest from May through September. Females exhibit higher K values than males.

Introduction

The gizzard shad is considered one of the most important forage fishes (Bodola, 1965; Lagler and Applegate, 1942; Lewis, 1953; Jester and Jensen, 1972). They represent an important species because they can utilize plankton and detritus as a food source (Bronoski, 1975; Tiffany, 1921a; Tiffany, 1921b; Jester and Jensen, 1972). Gizzard shad serves as forage for 17 important game fish (Miller, 1960), and may serve as the primary source of forage for most game fishes (Dubets, 1954; Schneidermeyer and Lewis, 1956; Jester and Jensen, 1972). As stated by Hubbs (1934), ''The gizzard shad is the most biologically efficient of all forage fishes''.

The initial analysis of the gizzard shad population of Crab Orchard Lake, Williamson County, Illinois, was performed by Lewis (1953). Lewis postulated that large die-offs of gizzard shad may control the age and size composition of the population. Reanalysis, therefore, serves as a comparison of the shad population over a 25 year period. It also provides qualitative data about this important forage fish.

Materials and Methods

A total of 1117 gizzard shad were collected by electro-shocking and seining from Crab Orchard Lake, Illinois, between March 1976 and February 1977. In order to obtain a representative sample of the fish population, three different homogeneous collecting areas which were ecologically similar, high in plankton and benthos, with depths ranging between 1 and 3 meters, were utilized. The electro-shocking device consisted of a 230 volt, 5000 watt, 180 cycle A.C. generator carried in a boat and connected to electrodes mounted on a boom extended from the bow of the boat. Seining was done in shallow waters and at a spillway. The seine was 50 feet long and had a ¼ inch mesh. Fish were collected either bi-monthly or semi-monthly and transported intact to the laboratory.

The fish were weighed to the nearest tenths of grams, measured to the nearest millemeter, sexed and aged. The latter was determined by means of the scale method.

Statistical analysis of the data was by means of SAS and was run on an Amdahl 470 computer.

Results

The coefficients of condition were determined for 1117 gizzard shad using the formula: $K^{TL} = \frac{W \cdot 10^5}{L^3}$ where K_{TL} = coefficient of condition, w = weight in grams, and L = total length in millimeters.

Comparisons of the coefficients of condition over a one year period (March 1976—February 1977) show females to possess highest K values from October through April (Fig. 1). Figure 1 also shows the K values to be lowest from November through April for both males and females.

The coefficient of condition decreases with an increase in the total length of the fish (Fig. 2). This decrease is seen also in the age groups which are directly correlated to the length of the fish (Fig. 3). Therefore, the lowest K values were recorded from gizzard shad greater than 310 mm (Fig. 2) which corresponds to the IV+ age class (Fig. 3).

The relationship between the length and weight in the gizzard shad was determined using the formula: W^5 CL^n where W^5 weight in grams, C^5 a constant, L^5 length in millimeters, and n^5 and exponent. The value obtained for the Log C was —15.11845 and the value for n was 3.05067 (Fig. 4). The gizzard shad population ranged in size from 49-353 mm (Figs. 2 & 4), and ranged in weight from 2.1-431.5 gms. (Figs. 2 & 4).

The gizzard shad population was comprised primarily of II+ and III+ fish. The maximum age fish obtained during this study was IV+ years.

Discussion

Gizzard shad constitute the principal forage fish in Crab Orchard Lake. It is for this reason that a thorough knowledge and understanding of their population is important and necessary.

The age class composition of the gizzard shad population has remained relatively constant since the original analysis of the population (Lewis, 1953). The population is comprised primarily of II+ and III+ year class fish with the third largest group being the II+ year class fish. The IV+ class represented less than two percent of the total sample size of gizzard shad.

The coefficients of condition varied greatly from those given by Lewis (1953). Lewis (1953) found the mean K value to be 1.82, whereas, the present study reveals a mean K value of 0.86.

The coefficient of condition of the gizzard shad were greatest from May through September (Fig. 1) and consistently lower from October through April for both sexes (Fig. 1). Differences in K values may be attributed to parasites. The acanthocephalan, *Gracilisentis gracilisentis,* is a highly pathogenic parasite (Jilek, 1979a). The degree of pathology produced by this parasite can be compared to the normal histology of the uninfected gizzard shad intestine (Jilek, 1979b). *Gracilisentis gracilisentis* may be in part or totally responsible for this marked decline in the K values since its seasonal periodicity (Jilek, 1978) coincides with the period of lowest K values.

The coefficient of condition also decreased with increasing age/size of gizzard shad (Figs. 2 & 3). It should also be noted that larger fish are more heavily infected with *G. gracilisentis* (Jilek, 1978). The increased K values for females during May, June and July may be attributed to an increase in gonadal tissue during the spawning season.

The length/weight relationship for the gizzard shad from Crab Orchard Lake provides a reliable fit whereby the age of the fish may be determined (Fig. 4). The length/weight relationship is also consistent with that of Lagler and Van Meter (1951) and Jester and Jensen (1972).

With the exception of the K values it appears that the overall population of gizzard shad in Crab Orchard Lake remains relatively stable. This may be due to the die-offs of millions of gizzard shad each year as postulated by Lewis (1953).

Acknowledgements

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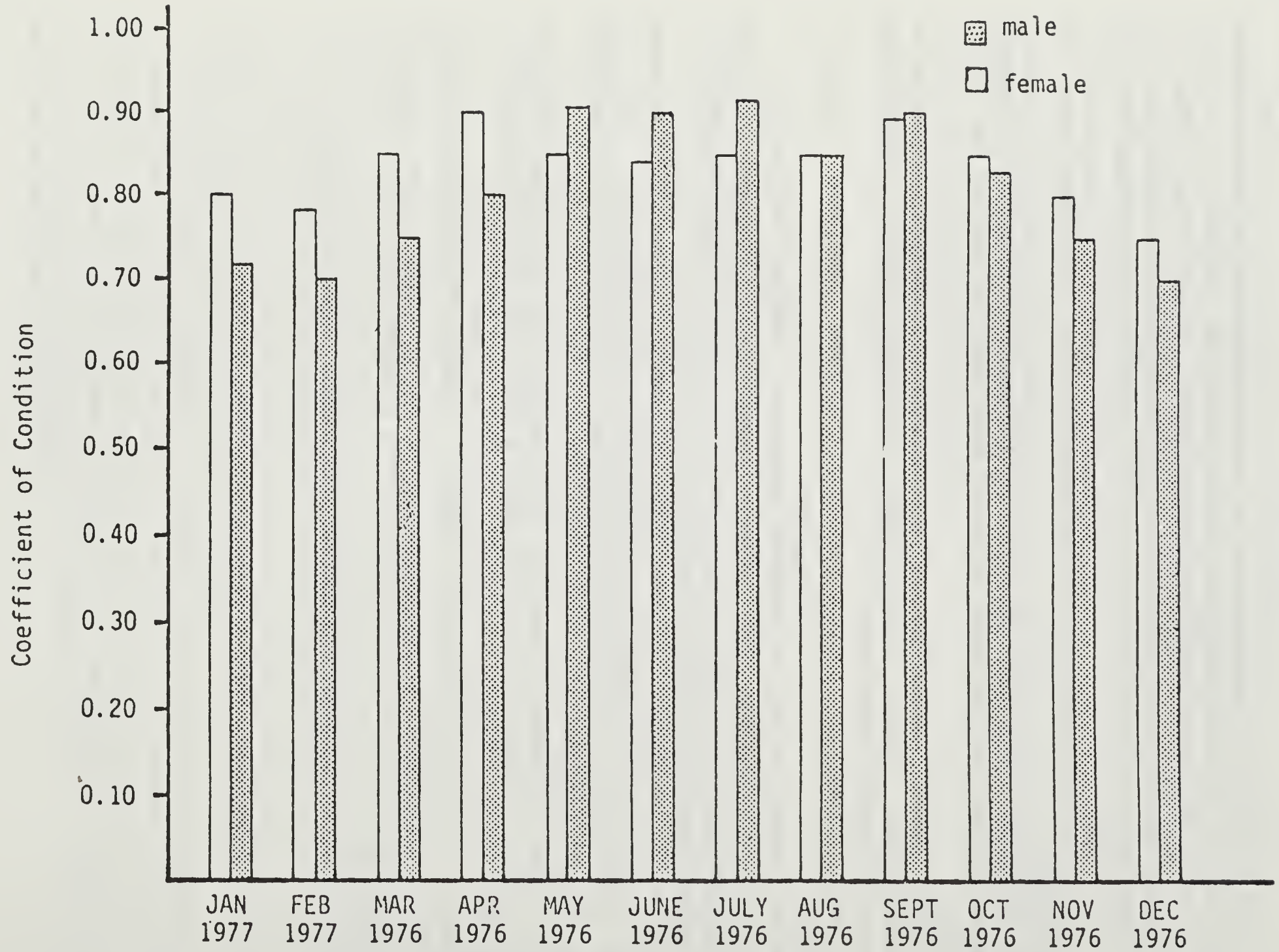
male
female
Coefficient of Condition
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
JAN 1977
FEB 1977
MAR 1976
APR 1976
MAY 1976
JUNE 1976
JULY 1976
AUG 1976
SEPT 1976
OCT 1976
NOV 1976
DEC 1976
Months

FIGURE 1

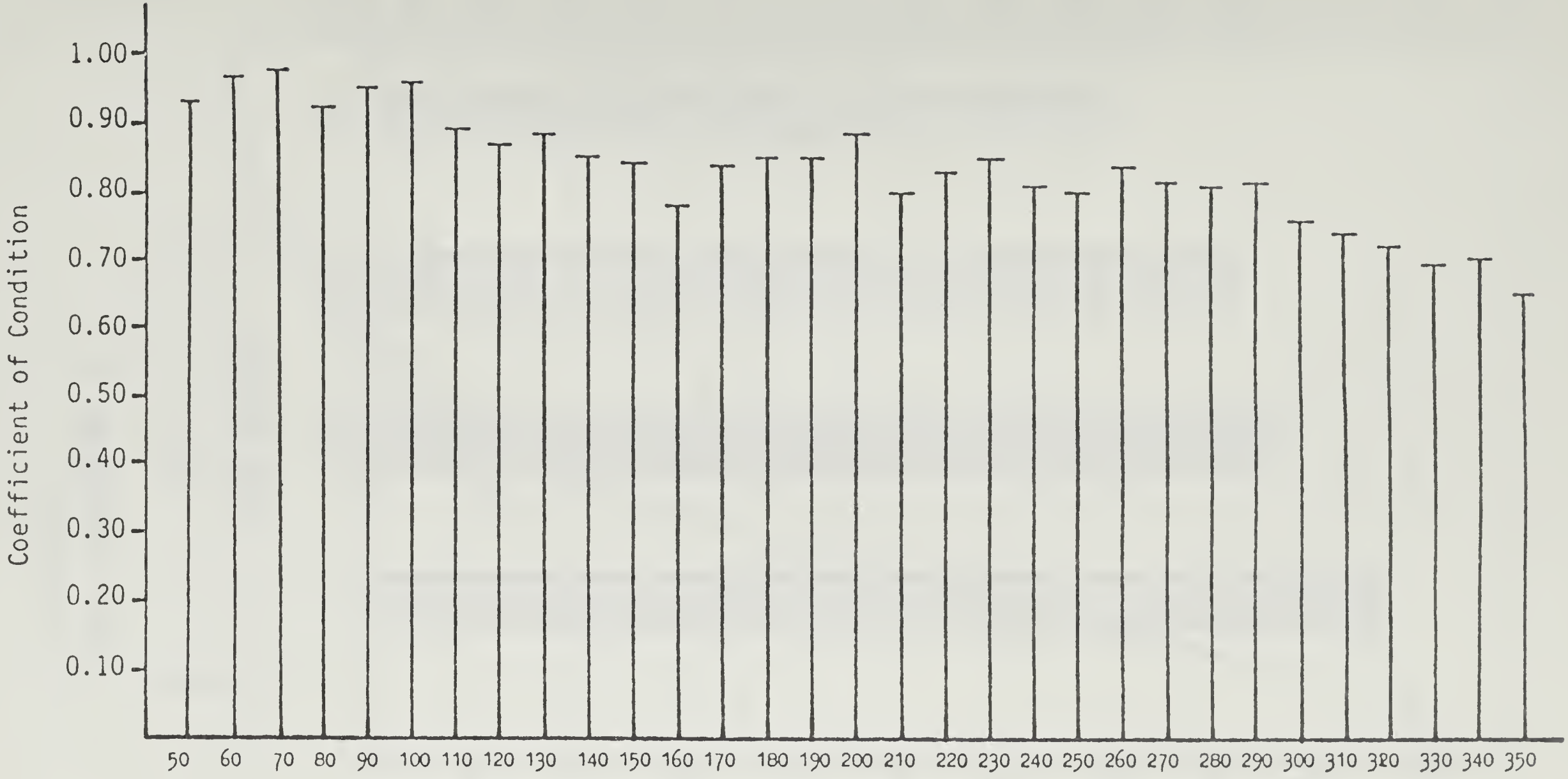
Coefficient of Condition
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350
Length (mm)

FIGURE 2

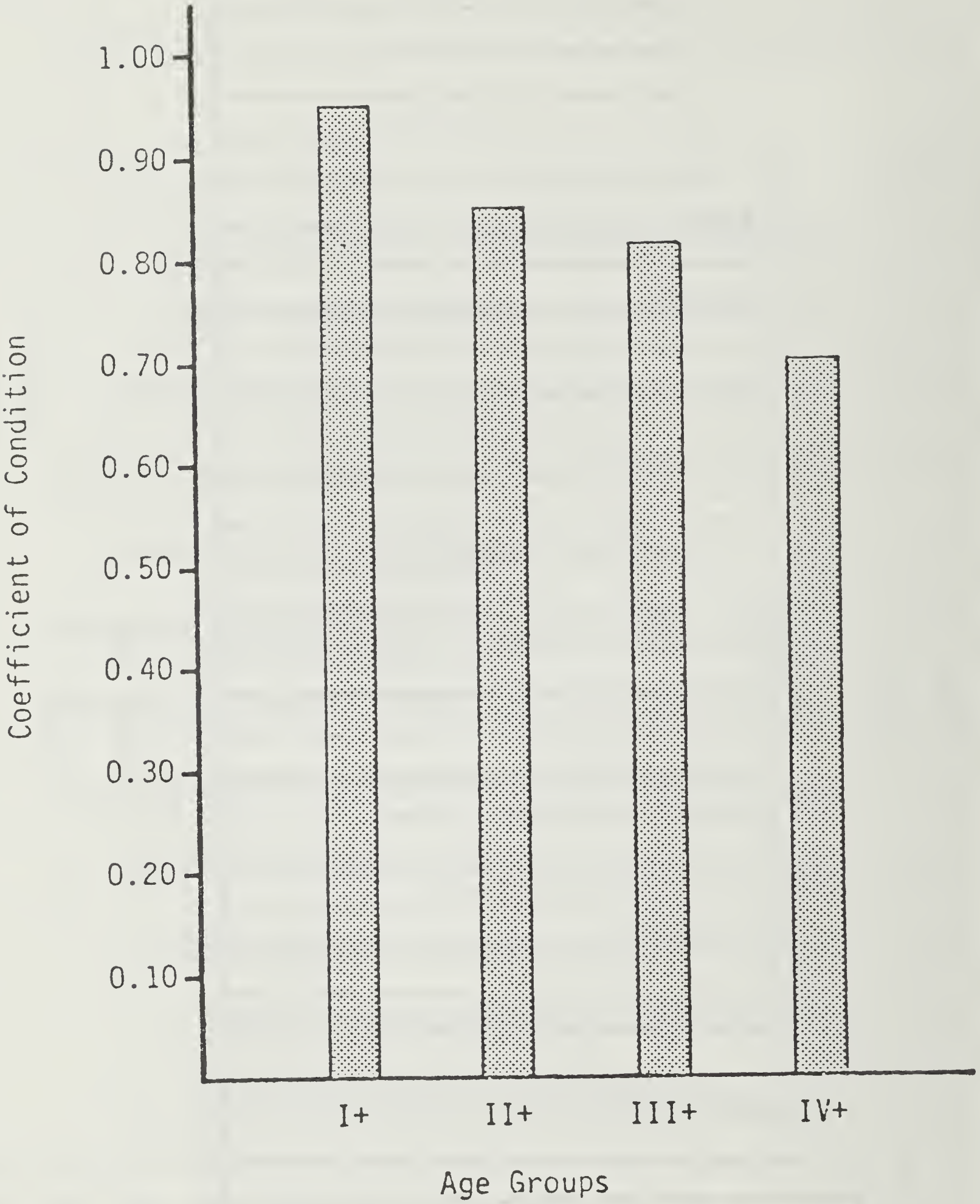
Coefficient of Condition
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
I+
II+
III+
IV+
Age Groups

FIGURE 3

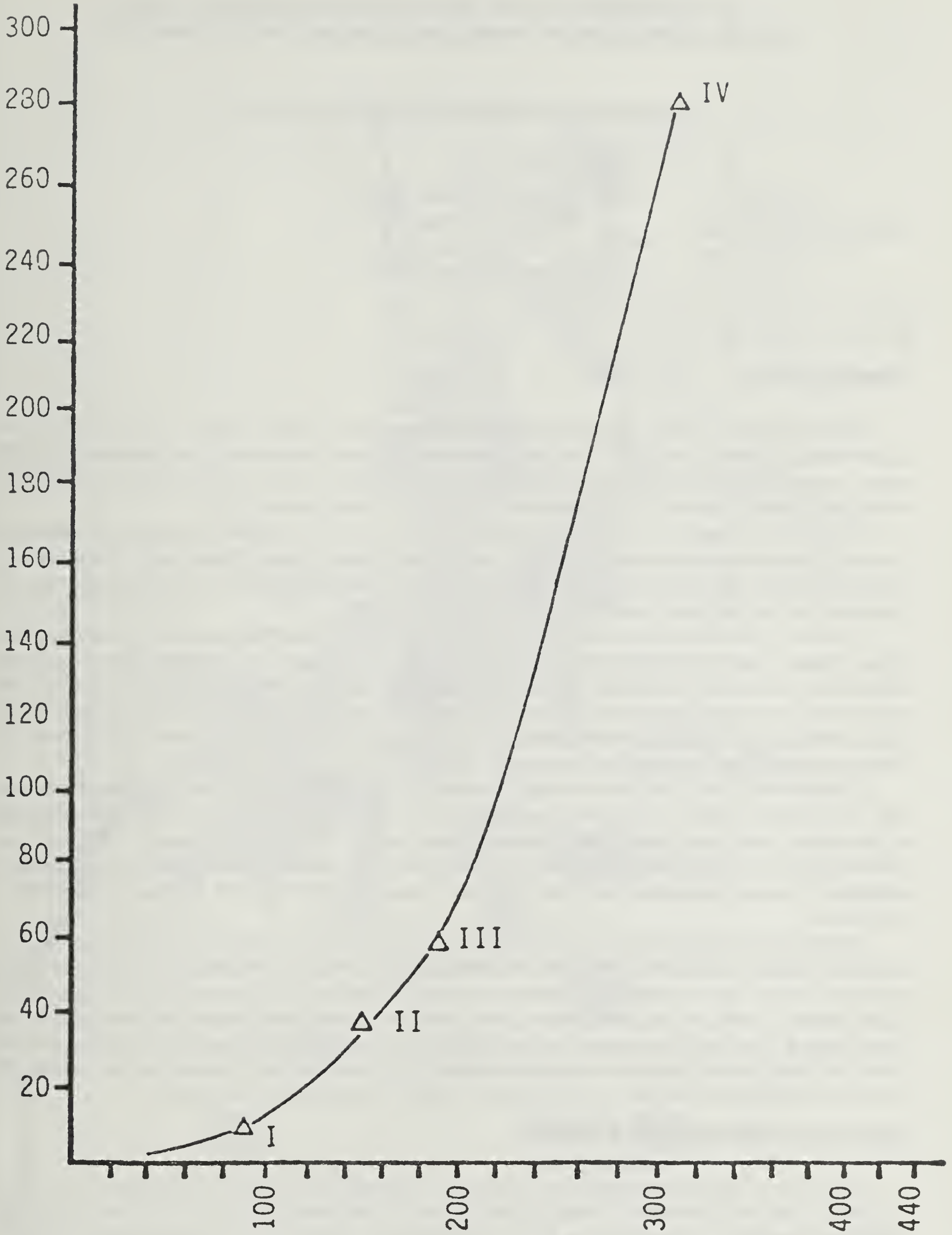
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Weight (grams)
I
II
III
IV
100
200
300
400
440
Length (mm)

Figure 4.

AN ASSESSMENT OF THE ECOLOGY OF FOX CHAIN OF LAKES AND THE APPLICABILITY OF IN-LAKE RESTORATION TECHNIQUES

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INTRODUCTION

The Fox Chain of Lakes, located in the northeastern part of Illinois (Figure 1), is one of the few glacial lake systems in the state. The interconnected bodies of water with a surface area of 6,850 acres, natural shorelines, picturesque beauty, and proximity to the city of Chicago combine to make the Chain a popular area for recreation and resort development.

The Chain of Lakes, in an advanced stage of eutrophication, experiences recurring problems of luxuriant nuisance algal blooms, periodic fish kills, and offensive odors. These and other symptoms of advanced lake eutrophy impair and interfere with the picturesque beauty of the region, and the aesthetic and recreational enjoyment of the Chain's waters.

A detailed 18-month investigation of the Fox Chain of Lakes was conducted by the Illinois State Water Survey (Kothandaraman, et al., 1977). The lakes develop distinct summer stratification and become totally anoxic below the thermoclines. Marked increases of ammonia, phosphorus, silica, and other end products of anaerobic decomposition of bottom sediments occur. Algal densities of 10,000 counts per milliliter or more are not uncommon in each of the lakes, and blue-green algae are the dominant species in the lakes.

A detailed nutrient budget developed for the lake system indicated that the total phosphorus and total nitrogen loading rates are, respectively, 10.3 and 86.0 $g/m^2/yr$, which are far in excess of the rates likely to be assimilated without giving rise to nuisance algal blooms. The nutrients released from the lake bottom sediments under anaerobic conditions in the deeper lakes during periods of summer stagnation are also sufficient to sustain algal growths of bloom proportions in the lakes.

Limiting the nutrient influx to the lakes is an essental step in reversing the eutrophic trend in the Fox Chain. Regional plans for pollution abatement in the Fox River watershed, including phosphorus emission control, are in various developmental stages in Illinois and Wisconsin. Illinois has taken a major stride in removal of phosphorus from municipal waste discharges and diverting waste discharges around the lake system where feasible. It is unlikely that nutrient influx into the Fox Chain of Lakes can be curbed to subcritical levels within the next few decades. In the interim, use of in-lake treatment techniques to enhance the Chain's water quality is justified.

PILOT LAKE RESTORATION SCHEMES

Figure 1 also shows the sites and the pilot lake restoration schemes investigated in the Chain of Lakes. Chemical treatment, using copper sulfate in the Mineola Bay of Fox Lake, resulted in significant decreases in algal counts after each treatment. However, the algal densities tended to

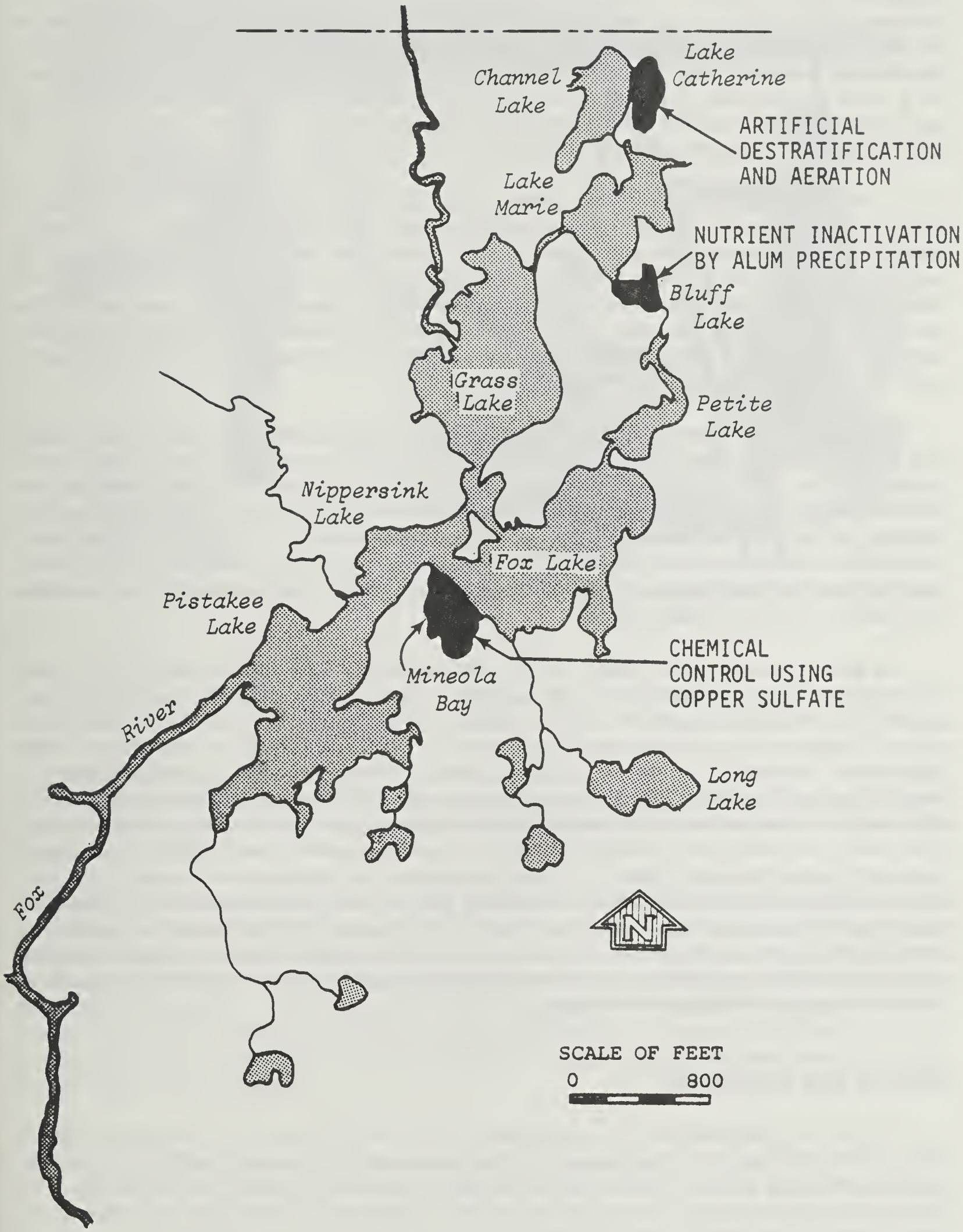

Figure 1. Fox Chain of Lakes in Illinois

increase within a week after chemical application. Nutrient inactivation using aluminum sulfate to precipitate phosphorus from the water column was investigated in Bluff Lake (92 acres). The immediate effect of the alum treatment was a dramatic improvement in lake transparency and a decrease in algal density. A marked drop in total and dissolved phosphorus levels was observed in the deeper portion of the lake. However, the beneficial effects of nutrient inactivation by alum precipitation were only transitory, lasting not more than a week. Consequently, this technique is not a viable consideration in an overall water quality management plan for the Chain. The method and rates of chemical applications for the aforementioned in-lake treatment techniques can be found elsewhere (Kothandaraman et al., 1978).

A unique aeration-destratification system (Figure 2), which is a combination of mechanical pumping and bubbled air aeration, was installed in Lake Catherine (150 acres). The system consists of a multistage deep well pump, aeration device, air hoses, and a mounting skid for supporting the unit on the lake bottom. The aeration system is also capable of applying and dispersing chemicals throughout the lake from a single location. The details of the installation of the aerator, reasons for the selection of this type of aerator, principles of its operation, and the hydrodynamic mixing of the upwelled hypolimnetic waters with epilimnetic waters are discussed in detail by Kothandaraman et al., (1979).

Installation of the device involved placing the unit on the bottom in 28 feet of water, about 750 feet from the southern end of the lake. Figure 3 shows the location of the aerator in Lake Catherine. *In-situ* observations for temperature, dissolved oxygen, and secchi disc readings were made at sampling station 1 in Lake Catherine about 2000 feet from the aerator. Samples were also collected at this location for chemical and biological evaluations. For purposes of comparison, similar observations and sample collections for analyses were made in the adjoining Channel Lake. Lake Catherine has maximum and mean depths of 39 feet and 16.7 feet, respectively,as compared to 35 and 13.7 feet for Channel Lake.

The aerator was started on May 9, 1979, and ran continuously until October 4, 1979, with the exception of three breakdowns in the operation. A thousand pounds of copper sulfate was applied on four occasions (June 21, July 5, August 2, and August 23, 1979) with the aid of the aerator. Copper sulfate only was applied on June 21. For the subsequent three copper sulfate applications, citric acid in the ratio of 2 copper sulfate to 1 citric was used as a chelating agent. A slurry of copper sulfate and citric acid was prepared in 55 gallon drums using lake water, and this slurry was then applied with the aerator by immersing one of the air suction hoses in the slurry. Soon after completing the chemical applications, water samples were collected from seven locations in Lake Catherine (figure 3) in order to examine the distribution of copper in the lake. Water samples were also collected the following day at these seven locations. Following the copper sulfate-citric acid applications on July 5 and August 2, 220 pounds of potassium permanganate were applied on July 11 and August 7, respectively. This was done primarily to oxidize the decaying algae after copper sulfate application and to avoid possible depression of dissolved oxygen concentration in the lake.

RESULTS AND DISCUSSION

Temperature. The pre-aeration investigations of the Fox Chain of Lakes (Kothandaraman et al., 1977, 1978) indicate that Catherine and Channel Lakes exhibit comparable stratification features. However, the water strata of Lake Catherine are colder than those of Channel Lake at depths of 15 feet below the water surface. During 1975 and 1977, surface water temperatures in these two lakes attained a maximum of about 27.5°C. The peak period of stratification occurred during July and August with the epilimnetic zones extended to 15 feet from the water surface in both lakes.

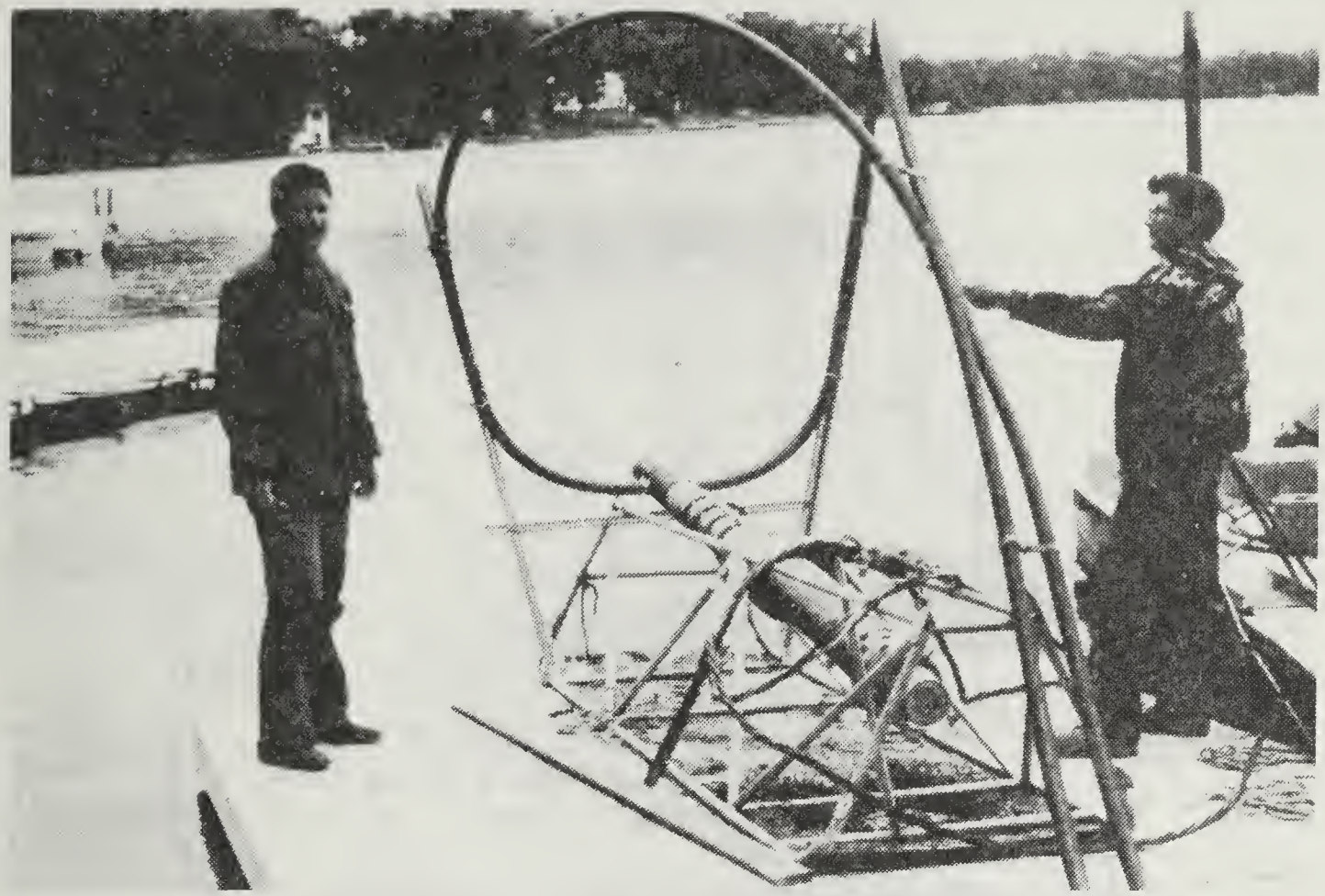

Figure 2. Aerator used in Lake Catherine

The isothermal plots for Lake Catherine at station 1, and for Channel Lake are shown, respectively, in figures 4 and 5. The periods of aerator shutdown either because of power failure, control panel malfunctioning, or vandalism are marked in figure 4.

The results indicate that the aerator kept Lake Catherine destratified, whereas Channel Lake stratified with the epilimnetic zone extending to only 15 feet from surface during July and August. During the extended period of shutdown (July 14 to July 26, 1979) of the aerator, Lake Catherine exhibited a tendency to stratify again. However, when the aerator was restarted, the lake destratified soon after. The temperature data show that the aerator destratified the lake completely. Water temperatures in Lake Catherine at 35 feet depth were 5 to 7°C higher than the temperatures for Channel Lake. Maximum observed surface water temperatures were also about 2°C cooler in Lake Catherine.

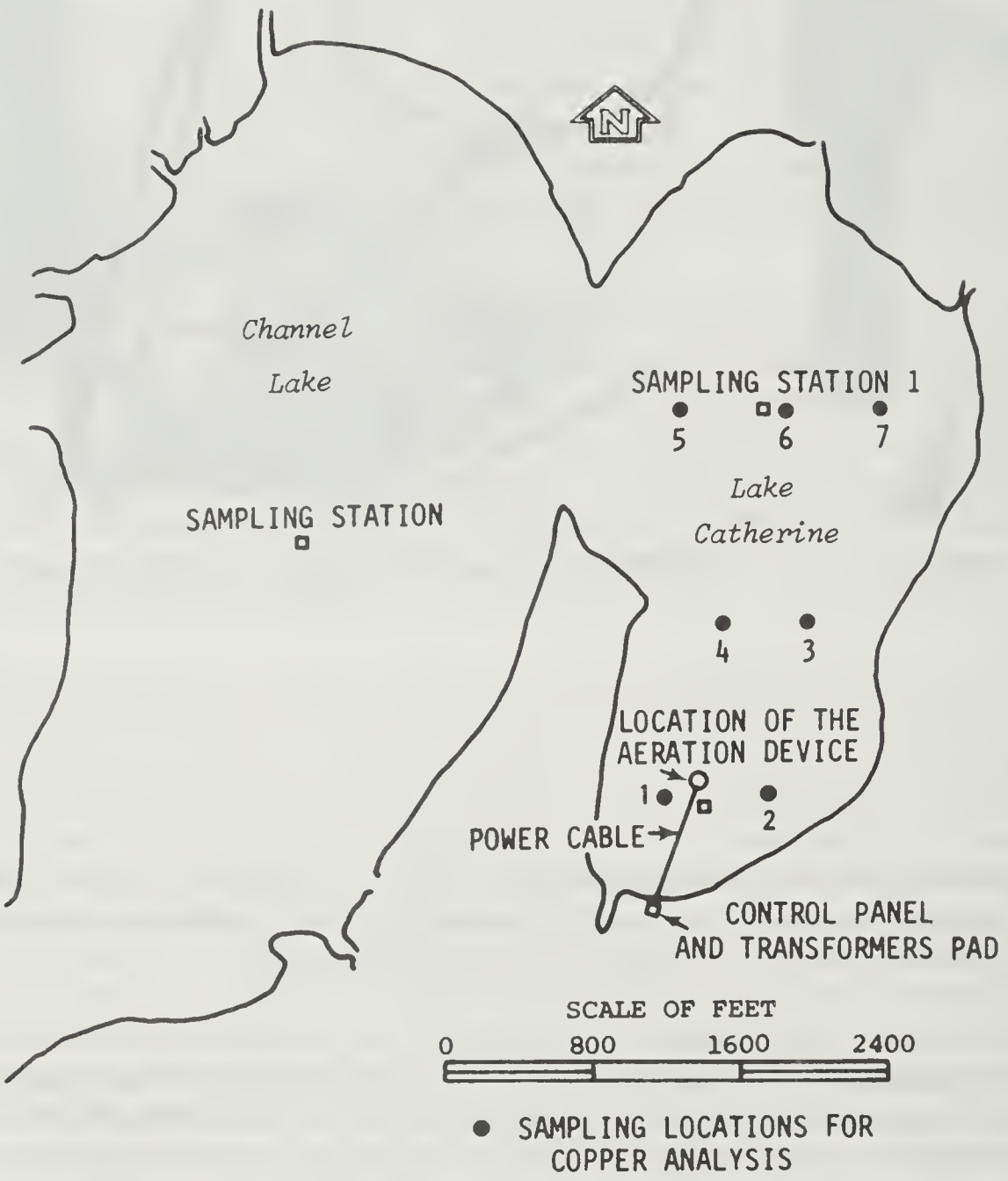

Figure 3. Location of the aeration device in Lake Catherine and sampling stations

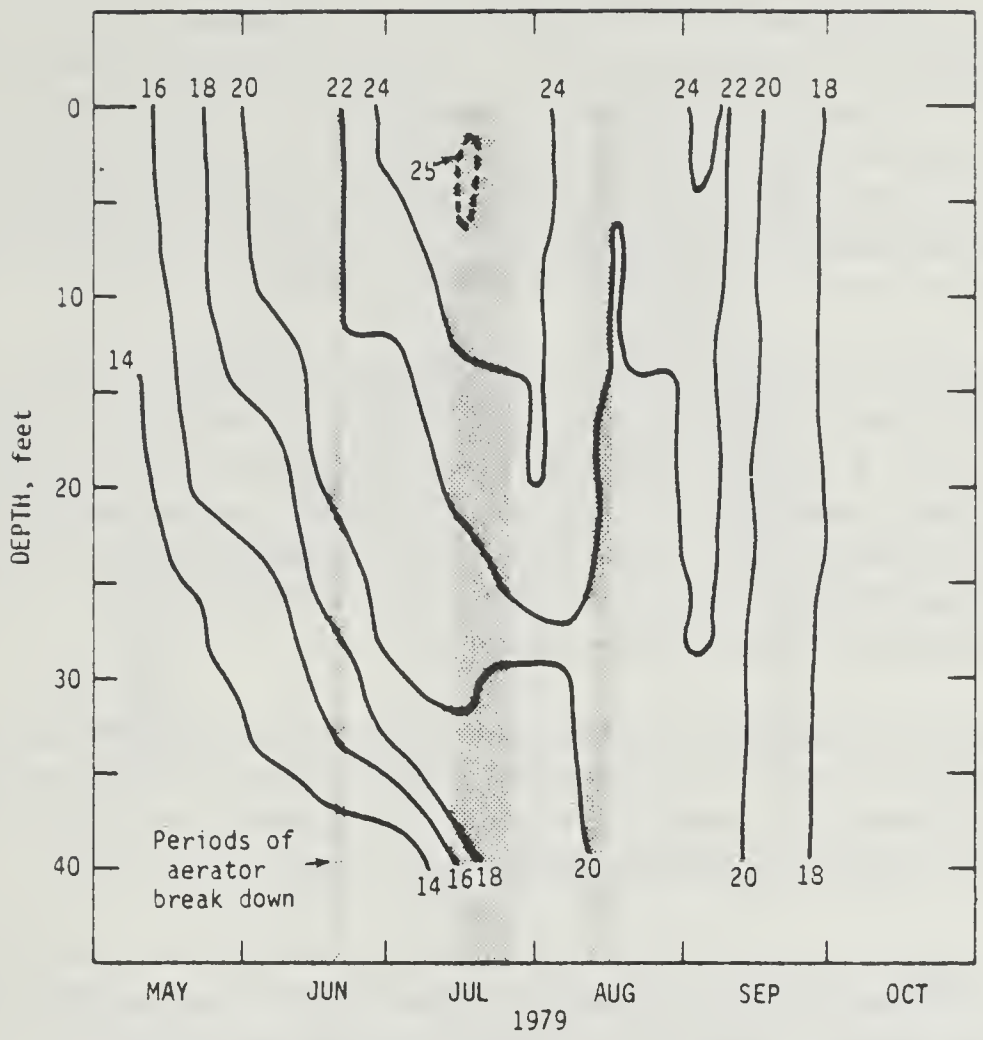

Figure 4. Isothermal plots in °C for Lake Catherine station 1

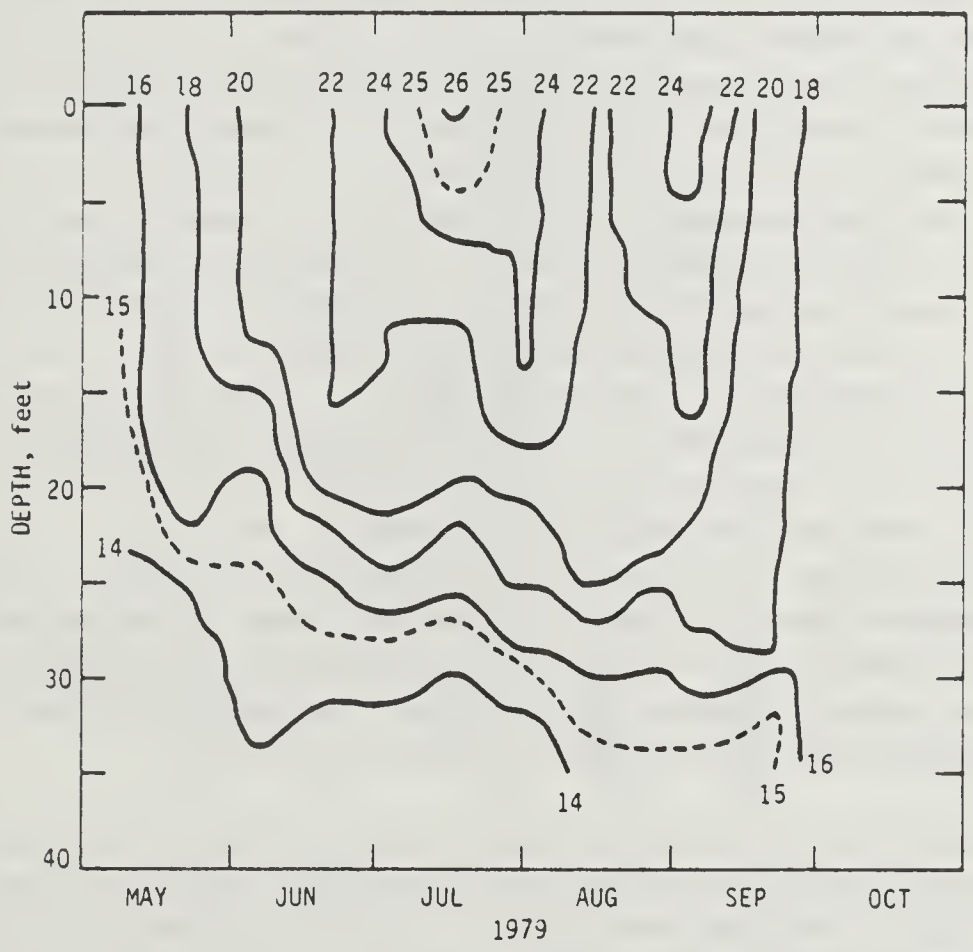

Figure 5. Isothermal plots in °C for Channel Lake

Dissolved Oxygen. Observations in 1975 and 1977 (Kothandaraman et al. 1977, 1978) of Lake Catherine and Channel Lake showed that the volume of the water column below the 15-foot depth was devoid of oxygen during summer stratification. July was the most critical month. Decomposition of algal silt in the profundal regions of these deep lakes and the subsequent oxygen demand of the products of decomposition are major causes of oxygen depletion in the hypolimnion. *In-situ* sediment oxygen demand determinations carried out in 1975 (Kothandaraman et al., 1977) indicated that a demand rate of about 16.5 g/m^2/day prevailed in these two lakes.

The effects of artificial destratification and aeration on the oxygen resources of Lake Catherine are shown in figure 6. Even though the aerator was started on May 10, and operated continuously for 2 months, with only a brief shutdown due to power failure, it is apparent that the oxygen demand exerted by lake sediments is much higher than the oxygen replenishment provided by aerator operation in the deeper layers. The anaerobic zone gradully extended upward. However, the rate of upward encroachment of the anoxic zone in Lake Catherine was very gradual and far less abrupt than that occurring in Channel Lake (figure 7).

Because of the extended period of shutdown of the aerator during the latter half of July, the anoxic zone extended to about 14 feet from the surface. Oxygen levels increased in the deeper waters with the resumption of aerator operation. The upward mobility of the anoxic zone in Channel Lake during 1979 was abrupt and occurred in May.

Secchi Disc Transparency. The temporal variations in secchi disc observations in these two lakes for the year 1979 are shown in figure 8. The days of chemical treatment in Lake Catherine to control algae are also noted on the figure. Secchi disc observations in Lake Catherine appear to increase after each copper sulfate application. These improvements in clarity could not be sustained for long because of the probable ingress of wind-swept algae from Channel Lake.

Phytoplankton. The temporal variations in the total algal densities in Lake Catherine and Channel Lake are shown in figure 9. Algal densities at the surface and mid-depth in Lake Catherine are generally less than in Channel Lake. The data presented clearly indicate a reduction in total algal counts in Lake Catherine. This is not just due to the redistribution of algae throughout the water column. If that were the case, there would have been an increase in algal densities in the deeper water samples of Lake Catherine compared with those of Channel Lake. The increasing of decreasing trends in the algal densities in Lake Catherine very closely follow the trends in Channel Lake. These trends in Lake Catherine sometimes go counter to the anticipated effects of copper sulfate application. Thus it can be concluded that the algal blooms in Channel Lake overwhelm the beneficial effects of aeration and chemical treatment in Lake Catherine. Nevertheless, there is a discernible trend in the decrease of algal count. Also, it is seen from figure 10 that there is a concomitant decrease in the dominance of blue-green algae in Lake Catherine. The ratio of blue-green to total algae is less in Lake Catherine than in Channel Lake, particularly during August and September after the prolonged break down of the aerator in July.

Benthic Macroinvertebrates. A more diversified benthic population was observed in Lake Catherine than in Channel Lake. The benthic population in Lake Catherine was composed of 58 percent *Chaoborus,* 37 percent Chironomidae, 4 percent *Hyalella,* and 1 percent Ceratopogonidae. in Channel Lake the benthos consisted of 94 percent ***Chaoiborus*** and 6 percent Chironomidae. *Hyalella* and Ceratopogonidae were found only in Lake Catherine.

Chemical Characteristics. The chemical quality characteristics of the surface and mid-depth water samples collected from these lakes had comparable values. However, the deep water samples collected close to the lake bottom were distinctly different as evidenced by table 1. Products of decomposition like alkalinity, silica, ammonia-N, and total and dissolved phosphorus were much lower in Lake Catherine than in Channel Lake. By the same token, chemical constituents of higher oxidative status like sulfate and nitrate were higher in Lake Catherine. The

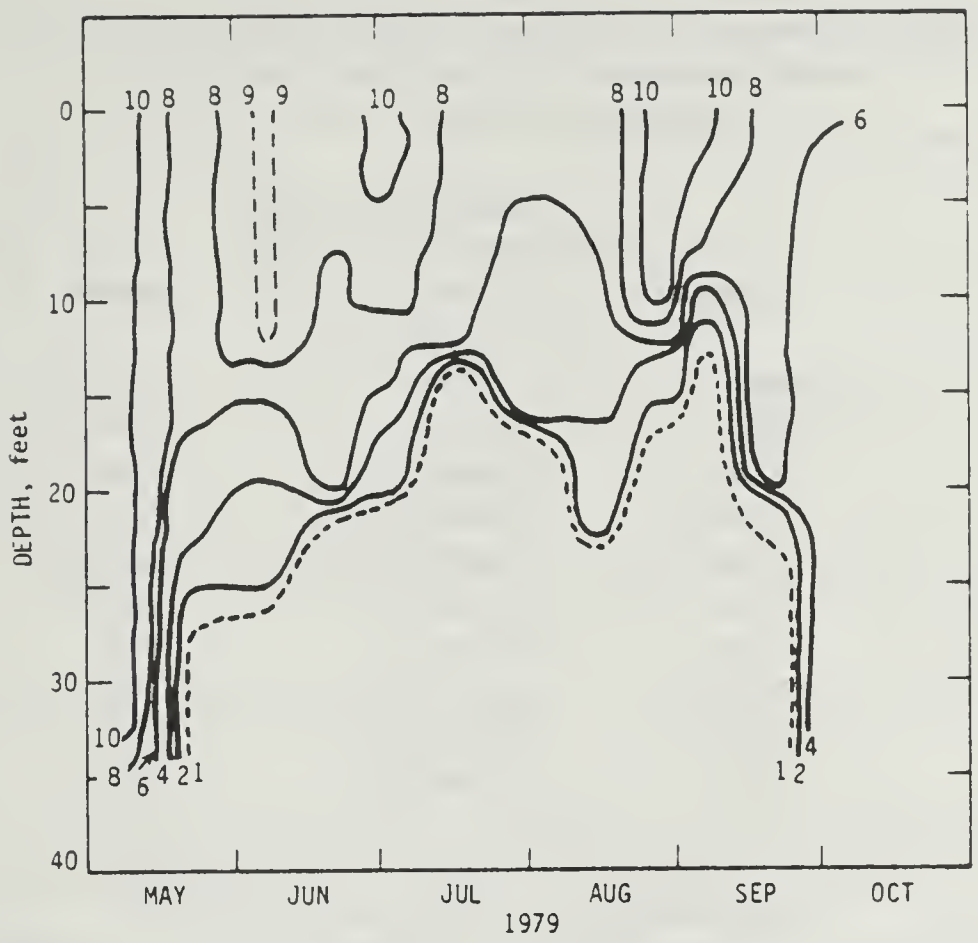

Figure 7. Isopleths of dissolved oxygen in mg/l for Channel Lake

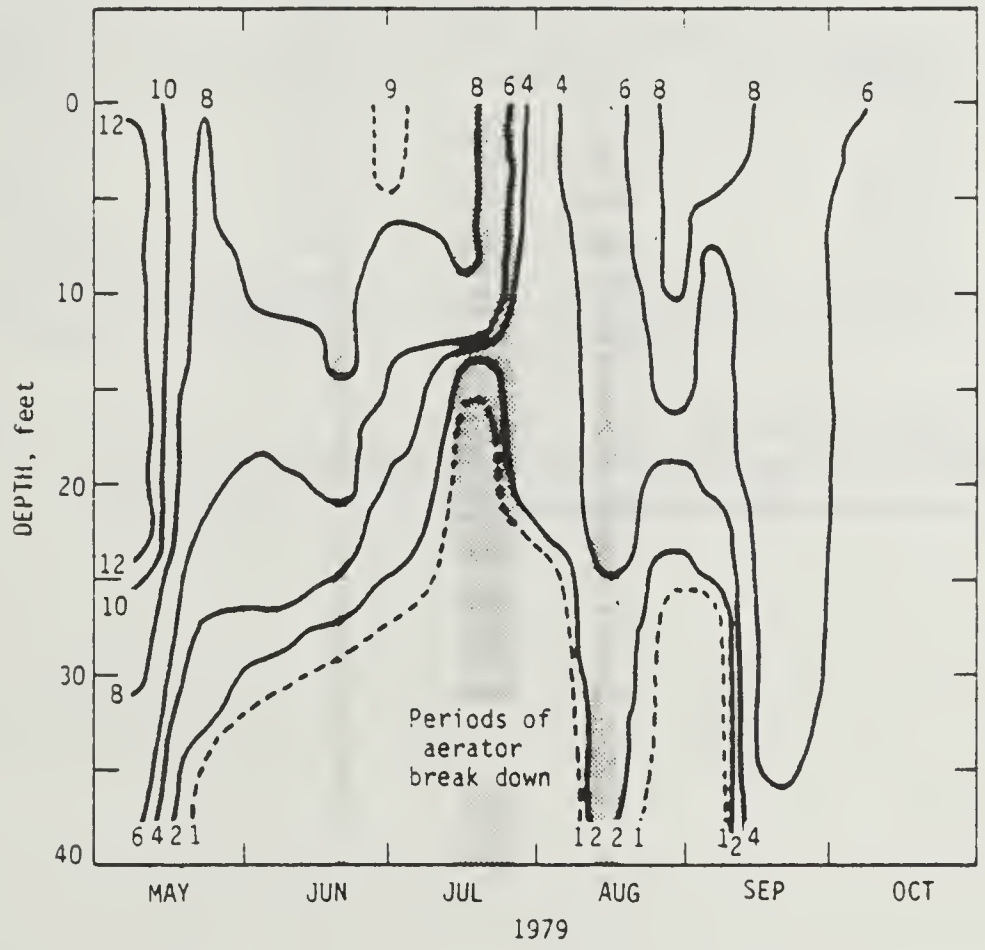

Figure 6. Isopleths of dissolved oxygen in mg/l for Lake Catherine station 1

Table 1. Summary of Chemical Quality Characteristics for August-September 1979 at Deep Locations of Catherine and Channel Lakes

Parameters	Catherine		Channel	
	Mean	Range	Mean	Range
pH		7.62-8.32		7.48-8.20
Alkalinity	169	157-177	202	182-230
Hardness	220	213-227	239	220-260
Sulfate	32.0	29.8-34.8	26.6	17.6-32.5
Silica	2.66	0.36-4.30	5.30	4.73-5.67
Chlorine demand	10.64	4.83-16.83	15.63	6.25-24.63
Total phosphorus	0.14	0.09-0.24	0.32	0.13-0.52
Dissolved phosphorus	0.08	0.01-0.21	0.21	0.04-0.32
Amonia-N	0.56	0.20-1.39	2.12	0.29-3.14
Nitrate-N	0.14	0.08-0.20	0.15	0.12-0.20
Total iron	0.21	0.08-0.35	0.23	0.08-0.67

Table 2. Copper Concentrations in Lake Catherine (Concentrations in milligram per liter)

Locations	6/21/79*	6/22/79	7/5/79*	7/6/79	7/11/79
1A	0.08	0.03	0.82	0.11	0.03
1B	0.23	0.08	0.07	0.15	0.07
2A	0.08	0.02	0.02	0.13	0.03
2B	0.29	0.03	0.11	0.15	0.05
3A	0.00	0.02	0.28	0.10	0.02
3B	0.25	0.03	0.07	0.19	0.02
4A	0.00	0.03	0.04	0.02	0.02
4B	0.02	0.02	0.12	0.15	0.05
5A	0.00	0.00	0.02	0.07	0.02
5B	0.10	0.02	0.07	0.07	0.02
6A	0.02	0.02	0.06	0.03	0.00
6B	0.04	0.02	0.07	0.07	0.06
7A	0.00	0.00	0.09	0.15	0.02
7B	0.04	0.02	0.09	0.10	0.05

Note: 1A = surface sample at sation 1
1B = sample at 5 feet depth in station 1 and so on
* = date of copper sulfate application

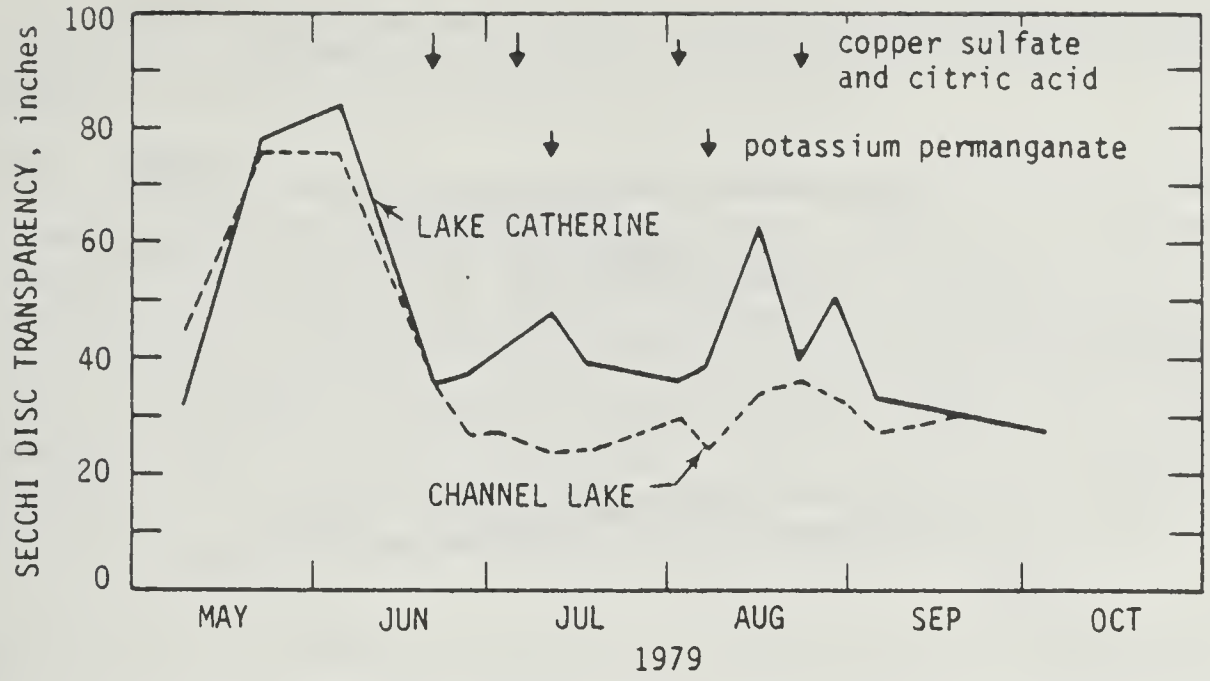

Figure 8. Transparencies in Lake Catherine and Channel Lake

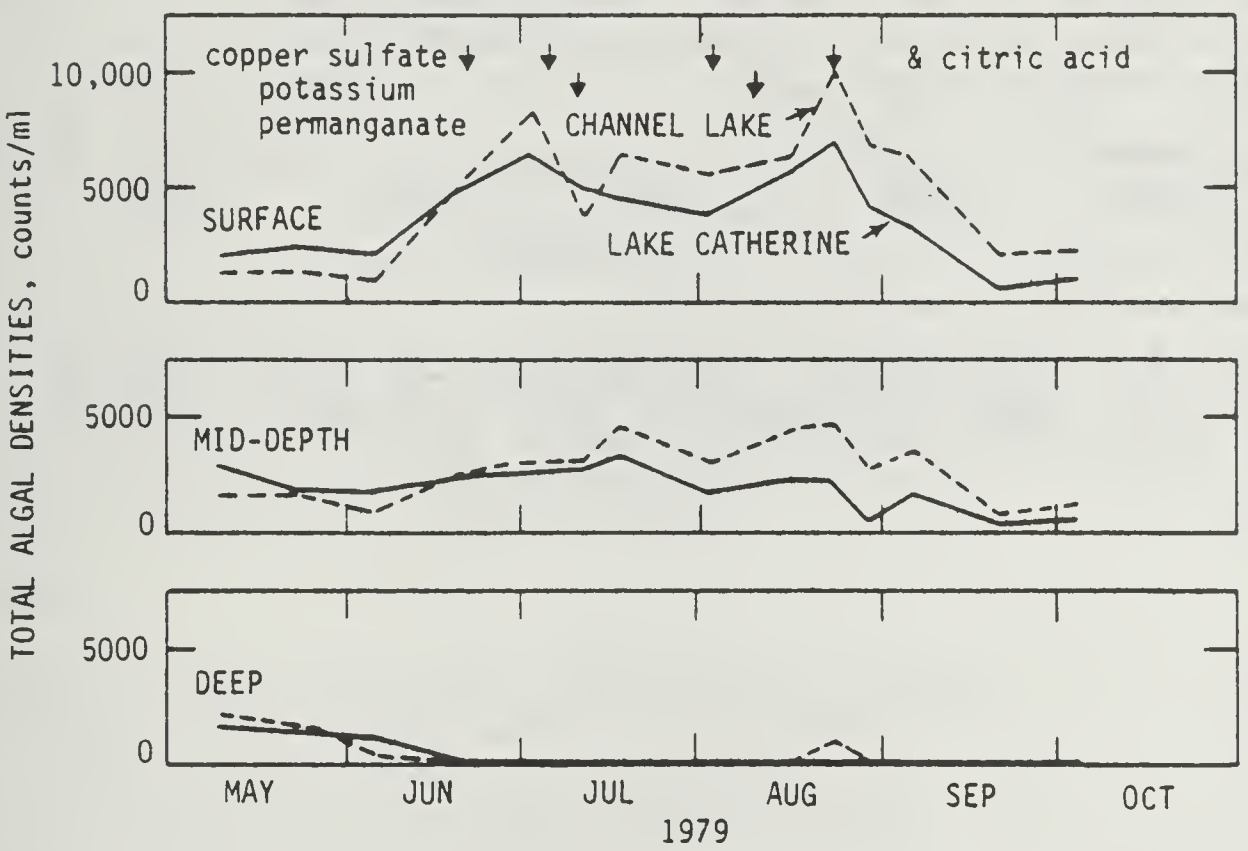

Figure 9. Total algal densities in Lake Catherine station 1 and Channel Lake

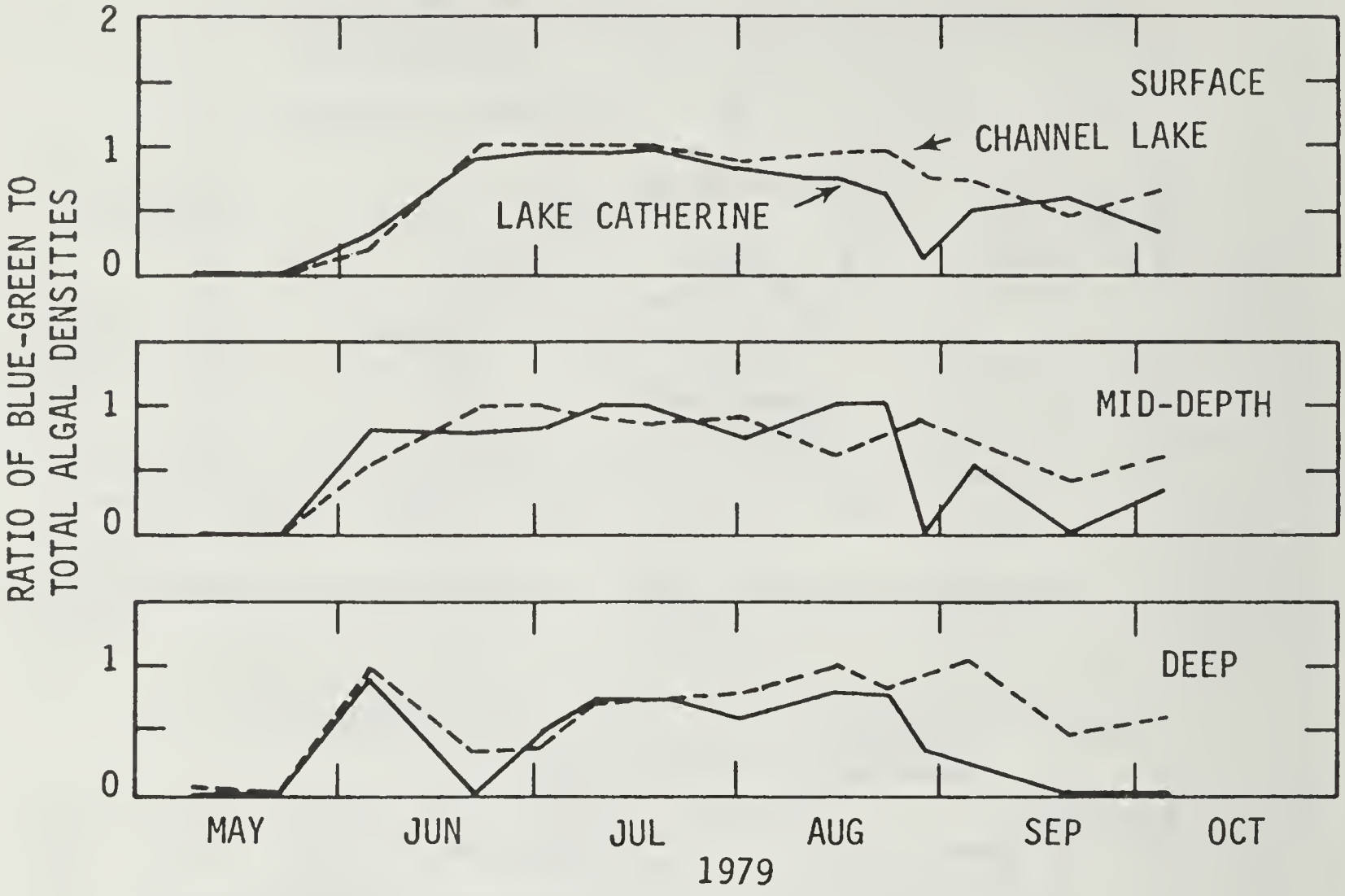

Figure 10. Relative dominance of blue-green algae in Lake Catherine and Channel Lake.

releases of phosphorus, nitrogen, and silica from bottom sediments were all reduced by half or more in Lake Catherine. Chlorine demand, which is a measure of the oxygen demand potential, had also been significantly reduced in Lake Catherine due to aeration.

Chemical Treatment. Copper sulfate was applied to Lake Catherine on four occasions during June through August 1979. The first lake chemical treatment on June 21 was only with copper sulfate, whereas for the remaining three applications, copper sulfate was chelated with citric acid prior to lake application. Results of copper analyses for the first two applications are shown in table 2. Copper concentrations in the lake water samples were much higher, and copper in solution persisted much longer when the copper sulfate-citric acid complex was used. Potassium permanganate was applied on July 11 and August 7, a few days after the application of copper sulfate in each case. Since potassium permanganate is a strong oxidant, it oxidizes decaying algal cells, thus relieving the potential demands on the oxygen resources of the lake.

SUMMARY

A unique aeration-destratification system which is a combination of mechanical aeration and bubbled air aeration was installed in Lake Catherine. The aerator is capable of applying chemicals from a single location and dispersing the chemicals throughout the lake. Consequently, the efficacy of artificial lake destratification in combination with chemical treatment (chemicals used; copper sulfate, citric acid, and potassium permanganate) as a lake management technique was investigated.

The aerator destratified the thermal regime of the lake, and oxygen concentrations of 2 mg/1 or more were maintained to a depth of about 28 feet from the surface. The data gathered during the summer and fall of 1979 indicate that the combination of aeration and chemical treatments has several beneficial impacts on the lake; *viz*, decrease in algal abundance, shift in algal species make up to the more desirable greens and diatoms, improved lake transparencies, and a significant decrease in the release of products of anaerobic decomposition—ammonia, phosphorus, silica, etc.—from the lake bottom sediments. A more detailed account of the sampling procedures, procedures for chemical analyses, algae identification and enumeration, chemical applications in the lake, etc. is given by Kothandaraman et al. (1980).

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OBEAH: BLACK AND WHITE MAGIC IN THE BAHAMAS

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INTRODUCTION

As a result of in-depth contact with Bahamian citizens in 1975 and 1976 while doing research on the folklore and folkmusic of the island group, I became more and more aware of the pervasiveness of *Obeah*. Previously, I had tended to dismiss the topic as superstition or a series of folktales carried over from previous generations. Beginning in 1976, however, I turned my attention to Obeah to determine as precisely as possible just what it means in the Bahamas and what the implications of the practice might be in the society. Initial findings were set forth in a modest monograph (Hedrick and Stephens: 1977). At that time we attempted to set forth a definition of Obeah; to address the rudiments of the practice and to set down a few preliminary conclusions. We called for more extended and intensive field work in the Bahamas, working directly with Obeahmen and women and indicated that one of our informants had offered to teach the senior author how and why various Obeah practices and functions are carried out.

On April 30, 1979, the Wenner-Gren Foundation for Anthropological Research, through Grant 3332, provided partial funding for the additional field work. The month of July, 1979 saw Hedrick in the Bahamas continuing the work begun 3 years earlier.

What ensued and the conclusions drawn constitute an important part of this report. In tying together the threads of the fabric for this publication, I have drawn liberally on the preliminary report alluded to earlier and I wish to reiterate my esteem for the abilities of my former research assistant and colleague, Jeanette E. Stephens and here to acknowledge her major contribution to the overall study.

I wish, once again, to extend my deepest thanks to Dr. Timothy McCartney, Clinical Psychologist in Nassau, for his continued good humor and invaluable aid in pursuing these studies. My appreciation, also goes to Dr. Carroll L. Riley for his suggestions on the manuscript and for his critical appraisal of the work.

Without the Wenner-Gren Foundation grant-in-aid, this work literally could not have been done: I am grateful.

Background

In addressing Obeah, one addresses the supernatural, the occult and the world of spirits; but one also is confronted with practical, everyday ''bush medicine'', an abundance of psychological manipulation, and some very flamboyant characters. Obeah is white magic and black magic; it is sorcery; it is positive and it is negative; it can cure or it can cause harm. Bahamian Obeah, in its pristine form, is not ''voodoo'', nor is it quite like any other similar practice in the adjacent Caribbean region. It is most commonly confused with Voodoo, as practiced in Haiti, or with similar practices in Jamaica, Guyana, Guadaloupe, Barbados and Grenada. However, Obeah—as practiced in the Bahamas—is unique and may be contrasted as well as compared with any other similar practice in this hemisphere. Obeah is not a religion and there are no ''priests'' or ''priestesses''; there is no group practice (in fact, it is extremely rare to find Obeah practices utilized other than on a one-to-one basis), and there is no way to tell an Obeahman or woman met casually on the street. It is clandestine, but all-pervasive. As one informant has stated: ''Obeah, it's a natural fact.'' Dr. Timothy McCartney (McCartney 1976:3-4), a clinical psychologist in Nassau, underscores the prevalence of the practice:

> . . . I have been in contact with individuals who have been ''fixed'' (or hexed) and as a result are suffering from physical and mental pain. My interest in Obeah has led me to many an Obeah Man and Woman—going either as a patient or as a friend, interviewing and observing. I thought at first that I was seeing more people with ''obeah problems'', either because of my particular interest or because the word had gotten around that I was interested in this phenomenon. I even got to the stage that every patient that I saw was asked the standard questions as well as 'Have you ever been fixed,' or 'Do you think that you are fixed (or that someone has obeahed) you?' Imagine my amazement when nearly half of my patients answered in the affirmative to at least one of the above questions!!!

Comparison and Contrast

Traditional Bahamian Obeah and related practices can be considered distinctive and slightly conservative in relation to those of some other Caribbean areas (e.g., Haiti and Jamaica), since in the Bahamas there do not appear to be as many formal beliefs related to Obeah as in some other areas. In the Bahamas, for example, traditional Obeah is countered by the administration of additional Obeah (often employing bush medicine), while in Jamaica and elsewhere there is a formalized practice called Myalism (Williams, 1970:144) for that purpose. Myalism is the antithesis of negative Obeah, and it employs white magic and other rituals to counter Obeah's effects. Bahamians do not hold much belief in vampires as is the case elsewhere in the Caribbean. Also, they do not use several terms that are common elsewhere, such as ''loogaroos'' (vampires) (Bell, 1970:166), ''Jumbies'' or ''Duppies'' (ghosts) (Bell, 1948:17), and ''Wanga'' (a synonym for Obeah in some areas) (Williams, 1970:118). Lastly, traditional Obeah is not related to Voodoo, which is practiced primarily in Haiti. Voodoo is a religious cult comprised of elements of African religions and Catholicism. It involves group participation in ritual dancing, trance inducement and animal sacrifice for ceremonial purposes (Metraux, 1959:15). Thus, Voodoo varies considerably from the individual client-practitioner relationship directed at effecting some specific result through use of sorcery, which characterizes Obeah. With the influx of Haitian practitioners, however, the term ''Voodoo'' is being used more and more, even when referring to palmists, fortune tellers, etc.

Defining Obeah

It is necessary to set the parameters of discussion for this paper. Although a substantial amount of doubt will be cast on the abilities of contemporary practitioners at a later point, it is well to understand just what the researcher is up against when he begins his exploration of this topic.

Obeah has been defined by several persons who observed its practice in the Bahamas or in other Caribbean societies. Patterson (1975:188) gives a good, concise definition of it:

> Obeah was essentially a type of sorcery which largely involved harming others at the request of clients, by the use of charms, poisons, and shadow catching. It was an individual practice, performed by a professional who was paid by his individual clients.

Speaking in reference to the Bahamas, McCartney (1976:56) states:

> Obeah is the phenomenon of the supernatural. It renders evil or good; makes dreams come true; influences individuals either for their demise or holding them in one's power. It can cause one to become rich or it can make one poor. It can cause an illness, either physical or mental or can cure any physical or mental problems. It can cause death! It is a type of spiritualism, surrounded by many tales of unexplained phenomena, and surrounded with superstitions that evolve into a plethora of articles (fetishes), bush medicine, signs and specific directions as to what one may do.

An earlier description is provided in the testimony of a Jamaican Government employee at an inquiry concerning civil disturbances in Jamaica (Williams, 1970:194):

> It is a two-fold art; it is the art of poisoning, combined with the art of imposing upon the credulity of ignorant people, by a pretence of witchcraft. Its effects are produced by poisoning . . . the general belief is that Obeah men are acquainted with the venomous plants of this country; their habit of practice in it is by imposing on the Negroes by means of charms and things of that kind. . . .(Report of the Jamaica royal commision, 1866:521).

Despite the allusions to poisoning—which undoubtedly did occur in an earlier age—there is absolutely no evidence to be found that poisons are employed in current Obeah practices in the Bahamas. It is conceivable that the toxicity level of some ingredients of "bush medicine" might cause adverse effects, or even death, for a patient, but that would be truly coincidental. The topic of bush medicine will be taken up at the appropriate time; suffice it here to say that bush medicine and Obeah are two distinctly separate subjects.

In the practice of Obeah, individuals wishing to cause something to happen to someone, that is, to have a "fix" set on another person, seek out the services of an Obeah practitioner. The practitioner listens to the client's description of the situation, then in exchange for a monetary payment he/she recommends what should be done to remedy it. Generally, he/she gives the client, or has the client procure, certain substances—herbs, special liquids, animal products, items from the victim's person (e.g., hair, fingernail clippings, an article of clothing, etc.). The practitioner gives the client instructions as to what to do with the materials—place them in the victim's house, bury them in the victim's yard, hang them in a tree, etc. If the client follows the instructions, the desired results supposedly will be achieved.

Obeah is practiced in numerous situations, for a variety of reasons. In the Bahamas, the practice tends to incorporate at least superficial aspects of both black magic (negative or evil intentions) and white magic (positive or good intentions). It is often employed to effect revenge upon someone for situations that may revolve around problems of jealousy between romantic rivals, marriage disputes, or the identification and/or punishing of thieves. In its more positive aspects, Obeah is used for curing ailments, which themselves are sometimes believed to be the result of Obeah, or in bringing good fortune to the individual in some endeavor.

Subsequent to three years of reading every scrap of information on the topic which can be located and after exhaustive (and exhausting!) hours of interviewing both clients and purported practitioners of Obeah, I am convinced of one major fact: The effectiveness of Obeah is dependent upon the belief in the validity and power of the practice.

The practice, among other things, generally involves the placing of special herbs, other substances or objects in specified locations in order to affect the behavior of someone. Usually, the desired end is for something negative to happen to a person, often in revenge for his/her prior actions. Obeah may also be employed to effect some positive result. The men or women who practice Obeah assure their "clients" that the desired results will be achieved by following their instructions. Their clients as well as the "victims," generally have deep faith in the abilities of the Obeah practitioners, and thus they usually do consider the Obeah magic to work.

Among portions of the Bahamian society, Obeah is still considered a very effective force for bringing about results, as its validity is trusted as a "natural fact" of daily life. For these groups of individuals Obeah serves as a means of gaining control of situations that are otherwise uncontrollable. Obeah brings to bear aspects of the supernatural on everyday problems, thus aiding in their resolution, or at least resulting in the afflicted client being able to cope with those problems.

The following section of this work deals with Obeah as I believe the majority of Bahamians view it. Not being a Bahamian, perhaps I will have erred in some of my interpretations of the Bahamian thought processes as regards Obeah. However, until called to task on the matter, I am comfortable with my facts and my deductions.

Obeah and Bush Medicine

In the Bahamas, Obeah remains closely associated with the use of medicinal folk remedies known as "bush medicine" (Higgs, 1974:1). Bush medicine, or "medicine from the earth" (McCartney, 1976:97), involves the administering of pharmaceutical plants to heal ailments. In its

practice, indigenous Bahamian plants are collected and processed into substances used to prevent, relieve or cure diseases (e.g., heart conditions, kidney disease, chicken pox, diabetes and tuberculosis) and various other disorders (e.g., headaches, muscular aches, boils, coldsores and fevers) (Higgs, 1974:5-20). The leaves, bark or other parts of plants may be employed in bush medicine practices. Often the plants are boiled into teas and taken internally. Also, they may be made into salves and applied directly to an ailing area or may be washed over the patient's body. The latter practice is called a "bush bath" and is rather common in the Bahamas. The plants often have genuine curing value, although perhaps not always to the degree credited to them. The unjudicious use of some of them may also have distinctly harmful effects. Their effective ability is of the same sort that has been demonstrated for pharmaceutical herbs throughout the world for centuries.

The past decade has seen a great proliferation of crosscultural studies of "traditional" medical systems (Fabrega, 1975). The increasing delivery and implementation of 'Western' health care in various geographic regions have been greatly facilitated by the rapidly accumulating body of anthropological information on health-related behaviors in different societies. In a recent study of traditional medicine on Bimini, Halberstein and Saunders (1978:177) have noted that "Recent transcultural investigations have demonstrated that medical beliefs, practices, equipment, and healing substances are extremely heterogeneous in form and usage across different populations . . ." and that "The ultilization of medicinal plants has received special attention in [their] research because it is an important biosocial phenomenon influencing patterns of health and disease. These authors point out that "the present findings suggest that the Bimini medical system has historically been efficacious in the treatment and management of many health problems on the island" (Halberstein and Saunders 2978:177). Given the fact that the herbs and grasses utilized on Bimini are identical to those used on other Bahamian islands, we may empirically conclude that bush medicine has been efficacious throughout the nation. Certainly, no Bahamian whom I know—including medical doctors—totally discredits bush medicine as a valid practice.

The practice of bush medicine requires an intimate knowledge of local plants, methods of their preparation and effects of their administration. Traditional Obeah practitioners tend to be among such knowledgeable people. The practitioners use the plants, which—as mentioned before—often do have actual curing abilities, to aid in achieving desired Obeah results.

> The Obeah person believes that plants absorb the cosmic properties of the sun, moon and planets and whether they are taken internally, used as a poultice or worn as a fetish or amulet, they convey to you the desired results. The occult magic of bush medicine is almost unlimited and is supposed to give the individual excellent physical, mental and emotional health which can be acquired in no other way (McCartney, 1976:98).

The use of bush medicine in Obeah thus helps to lend credence to the Obeah practitioner's claims of power through the achievement of verifiable results from the plants. Bush medicine is not synonymous with Obeah, however. While Obeah practitioners may use bush medicine—since it brings direct results (and thus credibility) to their art—the practitioners of bush medicine are not necessarily Obeahmen and may not use Obeah as a part of their work at all. McCartney (1976:186) summarizes well the nature and value of the bush medicine practitioners:

> There are many people who practice bush medicine and healing, and even though people look at them as obeah practitioners, they are not. These people have a genuine pride in their knowledge. They also have an extraordinary facility of dealing with human problems—physically, and emotionally.
>
> These native healers perform as valid a service as the trained professional. In effect, many of these "healers" are more effective than professionals, because not only do they share their clients' culture, communicate in language that they understand, but they live up to their clients' expectations.

The end result of Halberstein and Saunders' in-depth study is that

> ''The evidence suggests that the activities of native healing specialists and the use of medicinal plants have probably been highly adaptive in health maintenance and disease management in the population. Many of the plants possess chemical substances which may be effective against a number of conditions historically found in the population, including hypertension, gastrointestinal problems, diabetes, kidney and urinary disorders, pain such as in arthritis and rheumatism, and others.'' (Halberstein and Saunders, 1978:197).

There really can be no serious doubt but what bush medicine is a valid pharmaceutical practice in the curing of certain diseases. However, as frequently happens, quackery creeps into bush medicine also. In 1979, I heard of a tonic being sold for the purpose of increasing male virility. Through my informants, I found that a very bright young man who is a tour guide prepared this concoction and quite regularly made as much or more than his regular salary by selling bottles of the potion to his patrons as well as to some Bahamian customers. While there is no law against selling such materials, the fellow was a bit reticent to meet with me initially since he thought that, somehow, I represented the ''government'' or was a medical doctor out to do him in. Once he was assured to the contrary by mutual acquaintances, he quite openly came forward with samples of his brew and very freely discussed the contents and method of preparation and dosage. Although I purchased a two-quart Wesson Oil bottle full of the vile-smelling and suspicious-looking liquor for ''only'' $10, he assured me that he regularly gets from $15 to $25 from the male tourist for the same amount. I was given the ''Bahamian price.''

Although the majority of bush medicine prepared for internal consumption is prepared by boiling the various constituents, this young man simply steeped his contents in water for a period of approximately one week. He listed the contents, aside from fresh water, as being: Five Fingers; Strong Back; Love Vine or Dodder; Soldier Vine or Soldier Wine (also know as Stiff Prick or Stiff Cock), and Madeira Bark. Subsequent analysis of the plants and bark by a professional botanist corroborated the identifications which are listed with their taxonomy:

Five Finger(s), Feather Bed (*Tabebuia Bahamensis)*
Strong Back (*Bourreria Ovata)*
Love Vine, Dodder *(Cassytha filiformis (Cassythaceae)*
Soldier Vine, Soldier Wine, Stiff Prick, Stiff Cock ***(Tournefortia Volumbilis)***
Madeira Bark *(Mahogany bark)*

It will be noted that the above constituents contain gentisic acid (a phenolic acid), some alkaloids, sugar alcohol, methyl ether, etc. I am assured that a calming effect and a feeling of well-being can creep over a person having consumed several ounces of the liquor. The ''prescription'' which was given me was to use it as either an appetite arouser or as a sexual potency aid, i.e., an aphrodisiac. The dosage is as follows: First day, drink one glass of liquid prepared by mixing ¾ glass of the potion (known as ''Sexy Batch'' or ''Roots'') with ¼ glass of sweet milk and brandy; for the ensuing six days, one takes ½ glass of the brew, prepared with ¼ glass of liquor plus ¼ glass of sweet milk and brandy. Although a bit hazy as to exactly how much brandy should be included, he eventually felt that ''to taste'' would be appropriate, cautioning that ''too much'' might undo the good things promised by the therapeutic dosage.

McCartney (1976:99) lists a very similar recipe designed for the same purpose:

> One of the most famous Bahamian concoctions that males rely on, is the following bush tonic for fertility.
>
> (1) Gather the following from the bush:
>
> (a) Love Vine
> (b) Stiff Cock
> (c) Five Fingers
> (d) Gamalame

(e) Pine Bark
(f) Sweet Margaret

(2) If any one of these bushes cannot be readily obtained, one can substitute either ''old man'' or ''old woman.''
(3) Boil in a minimum amount of water these bushes and strain.
(4) Add a little sugar, boil again for five minutes.
(5) Add rum or brandy, boil for two minutes.
(6) Carnation cream (a little bit) can be added, but this is optional.
(7) Pour in a bottle (preferably a dark colored bottle) and allow to ''steep'' for about three weeks before drinking.

I cannot personally give witness to the efficacy of this medicine, nor have I found anyone who will admit to having drunk it—including the young man who made the batch I purchased. He did, however, say that while he could not guarantee results, some of his clients had assured him that it had worked wonders for them within hours. . . . The best rule of thumb for anyone wanting to sample any bush medicine of any type is to try to find a legitimate bush medicine practitioner through other Bahamians and, then, *caveat emptor*. Certainly, with amateurs abroad concocting brews from potentially dangerous herbs and materials, it is nothing to take lightly.

THE PRACTICE OF OBEAH

as Perceived by Bahamians

I should like to point out at the beginning of this section that what follows is primarily a description of the beliefs of *traditional* Obeah, as viewed by Bahamians. As will be noted further on, the current status of Obeah in the Bahamas is, simply, that it is rapidly disappearing if it has not, indeed, already disappeared. Interestingly, though, those who will discuss the matter still view Obeah in its historic context, i.e., what it was, not what it is. The following is my interpretation of how native Bahamians see the matter.

The practice of Obeah may be found at many locations in the Bahamas. It is most pervasive on Cat and Andros Islands, where it allegedly occurs in its most ''pure'' form. These islands have not been subject to as many recent socio-cultural changes from outside influences as some areas of the Bahamas. Thus, they are held by most Bahamians to be enclaves where the earlier, more ''traditional'' forms of Obeah have been retained. Obeah is supposed to be particularly prevalent on Cat Island, where apparently a large percentage of the population has a deep and serious belief in it. It is stated, for example (Forbes, 1940:191), that:

> The people of Cat Island do not like marrying outside their own settlements. They prefer to know all about the family, its blessings and its curses, from which they choose a bride or groom. Who knows what strangers might be able to do in the way of Obeah, about which everyone talks. . . .

Obeah is also reported on Acklins, Mayaguana, South Eleuthera, Crooked Island and the Exuma Cays (McCartney, 1976:78). It is practiced on New Providence (centering in the Nassauvian suburban area of Fox Hill) where it has come to employ more sophisticated paraphernalia, such as commercially produced ointments and cures, partially as a result of increased external influences on that island.

Obeah is practiced by essentially ''ordinary'' persons who happen to have the ability to effectively utilize its powers. Practitioners may be either men or women, Outwardly, they usually conduct unobtrusive lives and professions as average members of the society. As a rule, they do not wear any distinctive clothing or other personal items that denote their trade. There are no recognized costumes or insignia distinctive to them. An informant reports, however, that he does know of one Obeahwoman who wears a silver bracelet with supposedly secret magic inscriptions on it as part of her trade, although this does not automatically distinguish her as a practitioner. Obeah prac-

titioners are not manifestly wealthy as a group, although they do at times receive sizable payments for their services (which can amount to hundreds of dollars in difficult cases). The unobtrusive posture of the practitioners reflects the nature of the art: (1) because Obeah has been illegal, its practitioners historically have had to keep their identities a secret for fear of reprisals; and (2) the air of secrecy aids in maintaining the mystery associated with the practice, thereby enhancing the suggestion of its having special powers. An individual's success as a practitioner depends, to a large degree, on his reputation of having strong magical powers and the ability to achieve effective results. The more powerful the person is, the more he is feared and his abilities respected.

Obeah may be learned from several different sources. Some practitioners are said to be ''born with the gift'', which is discovered during their childhood and is encouraged to develop into a profession. Such individuals, or others who are interested but not inherently ''gifted'', learn the specifics of the art from older, established practitioners to whom they are ''apprenticed.'' Usually the teacher is a parent, grandparent or other relative, but it may be any person knowledgeable in Obeah. Practitioners may be reluctant to teach their knowledge to others unless they are assured of the latter's sincerity, for fear of divulging ''trade secrets'' which would diminish the aura of mystery, the prestige and the mystique of the practice. Other persons ''received their 'power' during adulthood with a 'vision' or, while 'in a trance,' were instructed into their art'' (McCartney, 1976:79). The same author (1976:78) reports that: ''Most of the older Bahamian practitioners are Bahamian born, but there is an increasing number of Haitian-Bahamians, Jamaicans and a few other nationalities who have quite a lucrative practice.'' Some novice practitioners are reported to have gone to Haiti or Jamaica to learn the art because it is so well-developed there.

Obeah practices are generally initiated by a secret meeting between a prospective client and a practitioner. This usually takes place in the home of the latter. The residences of several practitioners have been described as being well-stocked with the items of their trade. An account of a nineteenth century Obeah-man's house on Grenada (Bell, 1970:15,16) is illustrative of the situation:

> The dirty little room was littered with the Obeah man's stock in trade. A number of vials containing some sort of unholy liquor were lying ready to be handed over to some foolish negro in exchange for their weight in silver. In every corner were found the implements of his trade, feathers, bones of cats, parrots' beaks, dogs' teeth, broken bottles, grave dirt, rum, and egg-shells. Examining further, we found under the bed a large *conarie* or earthen jar containing an immense number of round balls of earth or clay of various dimensions, large and small, whitened on the outside and fearfully and wonderfully compounded. Some seemed to contain hair and rags and were strongly bound round with twine; others were made with skulls of cats, stuck round with human or dogs' teeth and glass beads, there were also a lot of egg-shells and numbers of little bags filled with a farrago of rubbish. In a little tin canister I found the most valuable of the sorcerer's stock, namely, seven bones belonging to a rattlesnake's tail—these I have known sell for five dollars each—in the same box was about a yard of rope, no doubt intended to be sold for hangman's cord, which is highly prized by the negroes, the owner of a piece supposed to be able to defy bad luck.

Contemporary practitioners also maintain stores of substances with which they perform their art, although not generally to the degree described by Bell.

Obeahmen tend to be skeptical of prospective clients and often refuse to help them or deny an ability to do so, until they are convinced of the person's sincerity and belief in the practice. For that reason, an individual desiring the services of an Obeahman is often introduced to him by a third person who already knows, and is known by, the practitioner. The client-practitioner relationship begins, generally, with the client describing his problem to the Obeahman and asking for the latter's professional help in alleviating it. The practitioner assesses the problem and, once convinced of the client's sincerity, prescribes a cure or performs it himself, in return for a given fee. The client then departs to execute his prescribed tasks and await the results of the Obeah magic.

The actual uses of Obeah, as well as the procedures employed and individual items used, varies considerably in contemporary contexts. Primarily, Obeah revolves around the practice of ''setting a

fix'' on someone or something; that is, casting a spell on him (it). By ''fixing'' someone, the Obeah practitioner may, for example, cause the ''fixed'' individual to do what the client requests of him. The ''fix'' thus refers to the magic itself. The ''set'' (or ''setting a fix'') refers to the procedures and materials involved in carrying out a fix. Such procedures are also referred to as ''dressing'' an item. For example, gardens are said to be ''dressed with Obeah'' (Bell, 1970:2) to prevent the theft of their contents. When a practitioner is about to perform Obeah, the room in which he works must be ''dressed'' (prepared), often by placing a candle in each corner. One prepares an item, such as a candle, to make it susceptible to or focused toward the Obeah magic.

An Obeah fix is set through the medium of fetish objects. In contemporary Bahamian practices, important items include: candle wax, ''seals'' (tablets bearing foreign, ''mysterious'' inscriptions on them), religious books (particularly the *Bible, The Sixth and Seventh Books of Moses,* and *Master Key),* grave dirt, egg shells, certain herbs, articles of clothing, and items from the victim's person. In addition a vast array of other mundane items may be used in any given instance. Poisons are not, today, heavily employed, although many potions comprised of ''bush medicines'' are used which may have somewhat deleterious effects on individuals. The objects or constituents are chosen because they are believed to have certain power, themselves, which is harnessed by the Obeahman, or because they are able to act as mediums for the practitioner's own power. Some items are used differently for black or white magic; some are used for either aspect. For example, in the context of black magic, passages from certain books are used, including *Seven Steps to Power, Black Guard, Seven Keys to Power* and *Master Key* (McCartney, 1976:87); whereas in white magic the *Bible* (particularly the Book of Psalms) is used.

The objects take their effect on the victims by being placed in their houses (often under their beds), sprinkled around their houses, buried under or in their walkways so that they step over them when leaving the house, or hung in a tree in their yards. Once the victim comes in contact with the item (whether knowingly or not), he will reputedly be affected by it, and the desired outcome of the fix will thus soon be achieved. In the context of negative Obeah (used as black magic), the outcome is said to entail such things as ''the loss of hair; unexplained swelling of the limbs or stomach; constant headaches or 'ringing in the ears'; unexplained outbreaks of boils or festering sores that do not respond to medication; the loss of the use of the limbs (not being able to walk, etc.) or deformity of the limbs, loss of sight,'' (McCartney, 1976:118), or sometimes even death. A common outcome professed for victims is that they will ''swell up and burst.'' To counteract the effects of a fix, individuals generally will consult a second Obeahman or-woman and receive a remedy from him/her in the form of curing substances or prescribed actions. Usually, the fix can be effectively countered in this way.

Obeah is used in solving a variety of problems—often in reference to crime dissuasion, romantic disputes, legal problems, revenge, finding lost articles, or curing ailments. A list of the kinds of results that reputedly may be obtained through Obeah is provided by Missick (1975:45):

Gain the love of the opposite sex
Unite people for marriages
Obtain property
Make persons do your bidding
Make persons love you, no matter who
Get any job you want
Make people bring back stolen goods
Make people lucky in any games
Cure any kind of sickness without medicine
Cast a spell on anyone no matter where they are
Get people out of lawsuits, courts or prison
Bring happiness to broken lives
Remove the sources of unhappiness

Such applications, or at least such intent, have been documented in informant interviews and written accounts of persons who have contracted for Obeah fixes or who have been victims of such fixes. The accounts may be used to graphically demonstrate the application of Obeah and its ef-

fects on believing individuals. While other, more "rational," explanations can often be given for occurrences attributed to Obeah, they do not diminish the value of Obeah explanations to some people.

Descriptions are given by several authors (e.g., Bell, 1948, 1970; Williams, 1970; McCartney, 1976) of the use of Obeah in protecting gardens and fields from thieves. An account published in 1905 describes a scene where Obeah had been set—a scene that is essentially the same as may be found today:

> At some of the islands, we found hanging to various fruit trees, fantastically draped bottles and sticks, which, we were informed, were charms to frighten away thieves and evil spirits. It is believed by the negroes that if any one but the rightful owners should eat the fruit from a tree on which this spell has been placed, he will swell up and burst. We were not fortunate enough, however, to see a demonstration of this remarkable effect (Penrose, 1905:415).

The contents of such bottles are reported by Bell (1970:4) as: "sea-water, with a little laundry blue in it, and . . . a dead cockroach floating on the top . . . some may have besides the cockroach, a few rusty nails and a bit of red flannel or such like. . . ." They may also contain a mixture of soil from a grave, floodtide water and a little air—earth, air and water elements that would have considerable combined power (Dupuch and Perfetti, 1961:34). Gardens may also be fixed by erecting a recognized Obeah sign—a diagonal red cross on a black background. It serves the same purpose as the bottles in warding off would-be thieves.

Obeah may be employed for detecting criminals, as well as dissuading people from illegal or antisocial activities. The following account is an example of situations in which positive Obeah is credited with bringing about justice:

> After Smith murdered his mistress, he took to the bush. Inagua had a lot of scrubland where the former Turks Islander could hide from his pursuers. An armed search party scoured the bush, but could find no trace of Smith. He thought he was safe.
>
> He was safe from ordinary searchers; but the old woman who attended his sweetheart's funeral told the other mourners that Smith would give himself up after six days.
>
> She told them so just after she had placed a fork, a stick and a stone in the coffin and had muttered a Creole incantation.
>
> Six days later Smith was found sitting on the steps of the courtroom. He was red-eyed and shivering in terror.
>
> I don' sleep for six day now," Smith complained. "Demon I can't see, he stick me wit' fork, hit me wit' stick and throw rocks at me." (Dupuch and Perfetti, 1966:92. 93).

In the context of romantic relationships and troubles Obeah may effect a reprisal against someone (often for revenge), or may be used in a positive, helpful sense. The following account, in which Obeah powers are supposedly involved in seeking revenge on a romantic rival, is paraphrased from a recent Nassau newspaper article (White, 1973:6). The incident began when two women had a heated agrument over the claim of one that her husband had been "sweet-hearting" the other woman. The other woman did not deny the charge, but said that it was the wife's fault for not satisfying her husband. The wife then shouted "Okay you going to get what you asked for. Between this day and tomorrow, you ger sleepunder the cotton tree . . . that's right, you just as well go inside your house and put your burying gown on." Unknown to the other woman the wife had a reputation of being an Obeahwoman. The police had heard of the incident and were suspicious of the wife, so they kept watch over the other woman's house during the night. She lived alone and they saw no one enter or leave the premises that night. The next morning the woman was found dead in bed, and the cause of her death was unknown, although no obvious foul play was involved. The neighbors all were convinced that is was the wife's Obeah power that had caused the death.

In a more positive context, McCartney (1976:82) relates how an informant applied Obeah to bring about the return of client's wayward lover;

> This man used to run around a lot with sweethearts and used to be very cruel to his wife. In desperation, she went to a Haitian Obeah man who 'set a fix' for her . . . . The lady was in-

structed to put this 'set' under his pillow for three nights, as he slept, . . . and this was supposed to stop him from 'running around'. Unfortunately, the marriage deteriorated and the man continued to beat his wife and stay out with his sweethearts. She finally came to see me and I asked her to bring me the set that the Haitian had fixed. Well, when I saw this, a length of candle wax bent into a U-shape, I told her no wonder he stay away. You see, he set it to cross her and he had to continue going out. . . . I told her to leave it with me and then I reset it with the ends of the ''U'' overlapping. . . . Shortly afterwards, the woman came to see me, very excited. 'Ma husband home!' From that time up to the present, this man has completely changed his life and he is now a devoted husband.

The use of Obeah to solve romantic troubles may also precipitate the application of counter-Obeah, as in the following quote from Dupuch and Perfetti (1961:36,37).

Fixing married couples so they quarrel and separate is a device commonly employed by sweethearts (a local term referring to mistresses).

One brown-skinned Eleuthera woman hexed a man and his wife. She made a mixture of Guinea pepper, grave dirt and dry dog manure, and sprinkled it over their yard. The wife packed up the children, left everything else behind and went to Nassau to see an obeah man. The obeah man told her how the brown-skinned woman put a hex on the yard.

''You goin' to catch hell!'' he told her.

''So what I mus' do?'' she asked.

''You go bring me white hankie, one egg.''

She brought them.

He performed a certain ritual with them, threw them away, and charged her £11 ($30.80) for his services. He gave her one small, orange-coloured package and told her to fasten it inside her dress over her bosom. He said she must never get it wet.

''Go home,'' he said. ''Go to your house.''

She did.

All went well until one day she went in swimming. She unpinned the package and put it up on a rock. The tide flowed in and carried it off. The same week, she and her husband started fussing again. She left him and never returned. He died.

The use of Obeah is reported in several incidents in which individuals attempt to use fetishes to obtain favorable verdicts in court. An informant states, for example, that such an outcome can be achieved by three methods. In one, the accused is instructed to walk backward on a grave, write the deceased person's name backward on a piece of paper, then put the paper in his shoe when he goes to court. By pressing on the paper during the trial he will supposedly make the prosecutor become confused and ruin his case. Similar results occur if the accused writes the prosecutor's name backward on a piece of paper, wraps the paper around an egg using new needles to secure it there, places the egg under the armpit or another concealed place, then presses the egg when the prosecutor speaks. Since the egg used is supposed to be fresh and uncooked, one can assume that the egg must break from time to time . . .! Certain oils rubbed on the accused person's body are said to harm the prosecutor's case when he walks near him. Portions of the Bahamian legal statutes that pertain to Obeah make specific reference to the use of such practices in courtrooms, as they are fairly common occurrences.

Obeah may be employed to effect revenge in innumerable situations where one party feels he has been intentionally wronged by another. In those situations it serves as an attempt to achieve retribution where, through the normal social and/or legal channels, such action is not obtainable for some reason. For example, Missick (1975:16-20) tells a story exemplary of the kinds of revengeful contexts in which Obeah might be used. His story entails a mother having a fix set on a teacher who hit her child unusually harshly. She had a book ''fixed'' with Obeah, then instructed her son to give it to the teacher. If the teacher accepted it, Obeah would supposedly work on the man and cause him to drown himself shortly thereafter. The teacher did not accept the book, however, and the boy was left with it. Soon after, the boy was himself drowned. The fix had thus ''backfired'' on his mother.

Obeah is called upon to relieve unexplainable, distressing situations which cannot be controlled by other means. Numerous stories occur in the Bahamas of "unnatural" happenings, such as the reportedly sudden appearances of objects or persons in abnormal locations (e.g., people passing through walls, showers of nails or rocks falling through solid roofs). To the individuals who believe the stories, the happenings usually are derived from Obeah and are alleviated by it. For example, McCartney (1976:63) relates:

> A patient of mine told me that, when she was seven years old, she was often awakened around midnight by moaning sounds that came from the upper partition of her room. These sounds would persist until the whole household would get up to investigate them. To their horror, one night they found a coffin in the living room of their house. They thought that someone was playing a terrible joke (prank) but this happening persisted over a period of months. They consulted their pastor who prayed for them and the house and also they consulted an Obeah woman who told them that it was a sperrid (spirit) that brought the coffin in the house. The Obeah woman promised them that she would ask the sperrid to leave them alone. This she evidently did, because a few days later the coffin no longer appeared in the house and the noises stopped.

The History of Obeah

Obeah is derived from West African practices of witchcraft which were transported to the Caribbean by African slaves. Some feel that in African societies witchcraft served as a means of coping with unexplainable or uncontrollable forces and events (Patterson, 1975). Among slave populations in the Bahamas and certain Caribbean areas, African institutions were officially suppressed by local governments. However, the need for some of them continued. The practices of witchcraft and sorcery as a means of maintaining social control went "underground": They continued to be practiced in a secret form throughout the Plantation period and after emancipation. Thus, in contemporary Bahamian society Obeah is engaged in by a subsegment of the population because it provides needed services to those persons, even though, officially, it is an illegal practice.

The word "Obeah," or "Obi" as it is sometimes called, comes from African terms related to some aspect of witchcraft. Various sources for the term have been suggested by researchers. Williams (1970:120) states that the word "Obeah is unquestionably derived from the Ashanti word Obayifo," which signifies "a wizard, or more generally a witch" (Rattray, 1916:48). Williams also states (1970:121) that by dropping its suffix the word "Obayifo" was shortened to "Obayi," which "was variously rendered by . . . whites as obeah, etc." The word was then shortened further to "Obi." Patterson, on the other hand, (1975:185, 186) states that "Obayifo is Twi in origin," and he suggests that another closely related Twi word, *obeye,* which refers to the spiritual beings that inhabit witches, is a more probable etymological antecedent of "Obeah." I feel that the antecedents of the Caribbean words are among these African terms, although which term is *the* source is undetermined, as there is such a close similarity in their sounds and meanings.

A popular interpretation of the phenomenon has it that in many West African societies witchcraft was a pervasive institution for maintaining social controls and interceding with suprahuman forces. The concept of witchcraft, in its African context, is defined as "a bad medicine directed destructively against other people, but its distinctive feature is that there is no palpable apparatus connected with it, no rites, ceremonies, incantations, or invocations that the witch has to perform" (Field, 1937:128). It thus involves the practice of black magic, and it is defined as an entity separate from white magic. Sorcery, which also involves black magic, is distinguished from witchcraft in that it makes use of fetish paraphernalia in order to affect some result. In African societies certain individuals were believed to possess and use supernatural powers, sometimes with the aid of fetish items, in negative or antisocial practices. Their practices were kept secret, but their effects were widely reckoned in any bad events that occurred. The threat of their power being unleashed against individuals who violated established rules served to control the social actions of the group.

It is assumed by several sources (Bell 1970, Williams 1970, McCartney 1976, and Patterson 1975) that, among the Africans transported to the Caribbean as slaves, there were some individuals who were intimately knowledgeable in witchcraft and sorcery, having secretly been involved in their practices in Africa. In the context of the Caribbean societies these practices were described as Obeah. Such practices were reported among slave populations on several Caribbean islands. Bell (1970:8,9) states, for example, that ''Before the emancipation in 1834 . . . the practice of Obeah was rampant in all the West Indian colonies.'' In more recent works, Obeah has been documented in Jamaica, Haiti, Grenada, Martinique, Antigua, Sta. Lucia, and Barbados, as well as in the Bahamas. It has been quite prevalent particularly in Jamaica and Haiti.

Obeah developed as a secret institution in the Caribbean under the framework of the Plantation system. Obeah practitioners were generally ordinary slaves whose particular knowledge and abilities in the art went undetected by the slaves' owners. Within the context of slave society, Obeah was primarily used in ''preventing, detecting and punishing crimes among the slaves'' (Patterson, 1975:190), as well as being used to seek revenge against someone. The method of punishment quite often involved subtle poisonings from toxic herbs or compounds, or the administration of harmful substances such as slivers of glass. Obeah was most often practiced on fellow slaves (Brathwaith, 1971:157,158), however, it was also employed by slaves to inflict harm, through poisoning, on slave masters. In the latter capacity, Obeah served as one of the few means available to slaves to retaliate against the system of slavery and the cruel treatment of slave owners. ''During the slave era many slave masters were afflicted with incurable sores, and many died, as a result of the deadly potions sprinkled on 'Massa's clothing or stirred into his food.''' (Cartwright, 1973:47). An account of such an occurrence is given by Brathwaite, (1971:157) quoting Marsden (1788:2).

> A neighbouring gentleman, as I hear, has now three negroes in prison, all domestics, and one of them grown grey in his service, for poisoning him with corrosive sublimate; his brother was actually killed by similar means. . . . Another agent, who appears to be in high favour with the negroes whom he now governs, was obliged to quit an estate, from the frequent attempts to poison him; and a person against whom there is no sort of charge of tyranny, after being brought to the doors of death by a cup of coffee, only escaped a second time by his civility, in giving the beverage, prepared for himself, to two young bookkeepers, to both of whom it proved fatal. . . .

The practice of Obeah was generally viewed by Caribbean governments as a threat to their social and political stabilities. Obeah was detrimental to the health and safety of individual members of the societies because of its use of poisons, and it was a menace because it invoked fear among the slaves. It was a more serious threat, however, to the political stability of the Plantation system. In addition to serving such rebellious purposes as the poisoning of slave owners, Obeah was used in actual slave insurrections. In 1760, Jamaican slaves who revolted briefly against plantation owners were led by Obeah men who used the supposed powers of their art to encourage the rebels. ''The influence of the Professors of that art was such as to induce many to enter into that rebellion on the assurance that they were invulnerable, and to render them so, the Obeah man gave them a powder with which they were to rub themselves.'' (Williams, 1970:116, quoting *Report of the lords . . .*, 1789).

As a result of the Europeans' fear of the influence of Obeah among the slave populations, laws were enacted in the Caribbean to prohitit its practice. In Jamaica, for example, laws were passed in 1788, 1816 and 1826 that contained clauses dealing with Obeah (Williams, 1970:164,167). Persons found guilty of practicing Obeah, through the possession of Obeah-related paraphernalia or the administering of poison, were generally given harsh sentences. On many Caribbean islands, particularly those with large slave populations, the penalties were deportation or death. In the Bahamas the Plantation system was never as successful as on some other islands, and Obeah does not appear to have been as great a threat to governmental stability in that nation. Bahamian laws against Obeah apparently were not as harsh as elsewhere in the Caribbean (McCartney, 1976:73).

Legal sanctions against Obeah greatly reduced the widespread rebellious threat of the practice. However, they did not eradicate the practice, which has persisted in diminished forms into modern Bahamian and Caribbean societies. After the end of the Plantation period in 1834, Obeah became

less destructive in effect, with decreased emphasis on the actual poisonings of individuals. It also became more tame as it incorporated elements of Christian religion in some of its rites.

In the Bahamas, Obeah is still an illegal practice. The law, last enacted in 1929 (The statute of law. . ., 1929) retains Obeah as a punishable offense:

Practising Obeah, etc.

254. Whoever practises obeah, or by any occult means or by any assumption of supernatural power or knowledge intimidates or attempts to intimidate any person, or obtains or endeavours to obtain anything from any person, or pretends to discover any lost or stolen thing or the person who stole the same, or to inflict any disease, loss, damage or personal injury upon any person, or to restore any person to health, shall be liable to imprisonment for three months.

255. (1) If it is made to appear, upon the oath of any credible witness, that there is reasonable cause to suspect that any person is in possession of any article or thing used, or intended to be used, by him in the practice of obeah or such other practice as is mentioned in section 254, it shall be lawful for any justice of the peace, by warrant to cause any place whatever belonging to or under the control of the person to be searched, either in the day or in the night, and, if any such article or thing is found in any place so searched, to cause it to be seized and brought before him to be secured for the purpose of being produced in evidence in any case in which it may be required.

(2) Where any such article or thing is found as aforesaid, the person in whose possession the article or thing is found shall, unless and until the contrary is proved, be deemed to be a person practising obeah within the meaning of the said section, at the time at which the article or thing was so found.

256. If, on the hearing of any case before any court, the court has reasonable cause to suspect that the accused or any witness in the case then in court has concealed about him an instrument of obeah, the court may direct the police forthwith to search the suspected person without a written warrant, and if any instrument of obeah is found upon him, he shall be liable to a fine of five pounds.

(Bahama Islands: statute law . . . , 1965:992).

Some cases of prosecution for Obeah practice have occurred recently; for example, in 1971, two women from the United States were found guilty and fined $40, for engaging in Obeah and theft: ''They were not aware that it was unlawful to practice the occult (in the Bahamas)'' (*Nassau Guardian,* Tuesday, December 14, 1971, p.4). For the most part, however, the Bahamian government, as most other Caribbean governments, does not rigidly enforce the law in reference to Obeah, as the practice of Obeah today is on a much less severe scale and does not pose the social and political threats that it did during the Plantation period.

Current Status

When a Bahamian is willing to discuss Obeah and is asked the question: ''Who was the greatest Obeahman in the Bahamas?'', the answer will almost unfailingly be either ''Pa Beah'' or ''Uncle Boy''. The former, who died just a few years past, was Zaccharias Adderley. Pa Beah was the acknowledged ''king'' of Obeah in New Providence and almost all other practitioners reportedly paid him homage. In reality, Adderley was a truck farmer who lived in Fox Hill (a suburb of Nassau, where his former house can still be seen) and who took up Obeah as a kind of side-line, according to one of his disciples, ''Killer'' McCoy. The hobby soon proved to be more lucrative than farming and he evidently spent a goodly portion of his last 20 years as a full-time Obeahman. He was approximately 70 years of age at his death. He was, if nothing else, a bit of a pragmatist. It is reported that he once commented: ''If people are stupid to gimme money I ain't too stupid not to take it''. Wonderous stories of his feats are still related today, particularly feats which tend to show his cunning in bringing to justice those individuals who stole things from his gardens. All of his successes are attributed to Obeah practices.

''Uncle Boy'', whose real name I have never learned, was the reigning Obeah monarch of Cat Island, where his fame is still extolled. Like Pa Beah, Uncle Boy was a farmer, with coconuts being his major crop. One famous story of his prowess at Obeah deals with his causing a man to ''swell up'' because he had stolen some of Uncle Boy's coconuts, but would not come forward and admit his crime. The thief continued to swell despite every effort to cure him and, ultimately, he died. Obeah had caused it.

These are but two of the real-life characters one encounters in the active folktales concerning Obeah. Today, the names one hears whispered are Mrs. Fowler, Phillip Lazaique, Mr. Rolle, ''Old George'' and ''Killer''. Each of these individuals is very real and, to one degree or the other, purportedly practice one form or the other of Obeah. Let us see, however, just how they performed during the 1979 field season during which time I had been promised I would see how and why Obeah works.

First, let us recall that Cat Island and Andros Island are reported to be the foci of the most pure forms of Bahamian Obeah today. On Cat Island, not one of the three individuals recommended to me by my prime informant in 1977 was to be found. Now, this may not seem too strange initially, but consider the fact that I was well known and came recommended by Bahamians as ''a man you can trust—he one good mon''. Having established myself within the infrastructure of Bahamian society over a period of some eight years, where everyone knows someone (and is generally related), there was/is no reason to even suspect that I would cause mischief or bring trouble to anyone. This was already known through my previous work and publications in and about the islands. Not only were the three Obeah practitioners not to be found on Cat, I literally could find no one who could suggest any specific individual now living there to whom I could even be introduced for the purposes of the study. And this is in one of the reputed cradles of Obeah.

Hence, I moved my scene of operations to Andros, the other bastion of Obeahdom. I knew that ''Old George'' was there and I had good reason to believe that he would see me with the introductions I brought. Imagine my delight to find that the rickety taxi, né stationwagon, lacking a functioning water pump, which met me at Andros Town's air strip was driven by an elderly gentleman who turned out to be none other than ''Old George''. During an interesting, almost brakeless ride with two stops for water in the radiator, I came to know the man very rapidly—not to mention his colorful vocabulary. After one week of interviews, interspersed with various monetary and liquid enticements, I learned essentially four things from this worthy: 1) Obeah was, indeed a ''wery pow'ful t'ing''; 2) he had not practiced Obeah in years (he was reluctant, now, even to admit he once had done so); 3) he was recognized as a locally important concocter of bush medicine—as he put it, he ''did bile good bush'' (a fact corroborated by other local informants) and, 4) if I wanted to talk to a really good Obeahman (sic], I should see Miz Fowlah in Nassau. I turned in every direction possible in the local area to try to find someone—anyone—who actively practices Obeah today. Two expatriate Americans who run a hostelry in the vicinity also could not or would not give me any valid leads. Andros was, therefore, another washout in the venture.

Hence, I returned to New Providence and its capital, Nassau, still in the hope of witnessing some good, Bahamian brand of Obeah. I went to my good and valuable friend, Dr. Timothy McCartney, who had indicated his every willingness to aid in my quest, for he is also totally fascinated by Obeah and has written the only serious approach to the topic in the Bahamas. It is germane to note that McCartney (1976:79) lists only eighteen people claiming to be Obeah practitioners: 7 in New Providence; 2 from Cat Island; 3 from Andros; 2 from Haiti; 1 from Jamaica; 1 in Freeport, Grand Bahama; 1 from Eleuthera and 1 from Long Island. As a result of these interviews, McCartney notes (1976:80) that ''Out of the eighteen Obeah practitioners interviewed, two of these greatly impressed me and appear to have extra sensory perception. . . . With the exception of these two practitioners, the rest were, to my mind, frauds, very clever ''con'' men and women doing a helluva business.'' This observation is doubly important to a white, American researcher since Dr. McCartney is both black and Bahamian, in addition to possessing the academic and research skills prerequisite to making such a judgment.

Back in Nassau, I turned my sights first on Mrs. Fowler, an erstwhile Obeahwoman resident in the Palmdale section of the city. I visited her place on three separate occasions, never to find anyone at home. On the third visit, through judicious inquiry, I was able to determine that ''Miz

Fowlah's off de island''. No amount of inquiry could determine precisely where it was she had gone nor when she was destined to return. Another blank drawn.

Phillip Lazaique (or Luazzi or Lazeke) is a Guyanese about 35 years of age, evidently permanently resident in Nassau who has built up quite a following. I had been warned that Mr. Lazaique was ''difficult'' to see and he certainly lived up to his reputation. He simply refused to see me. It was indicated that he had no time to ''mess 'round with that man''. It is this same Mr. Lazaique who figured in a lead story in *The Tribune* dated September 26, 1975. The article was entitled ''Man Cleared of Obeah Charge''. It read, in part:

> ''Several boxes containing lucky powders, incense, bits and pieces of paper with names written upon them and a couple of men's underwear were ordered returned to a 32-year-old Guyanese spiritualist today when a lower court judge found nothing unusual about him haveing them.
>
> What Philip Lazaique won't get back however is a fowl's egg with the names of several persons written on it. That exhibit, seized by officers who arrested the curly-haired Guyanese in July on an obeah practising charge was listed as destroyed, the court heard.
>
> ''Lazaique, who was represented by attorney Henry Bostwick, was freed after Chief Magistrate Mr. Wilton Hercules found there was a lack of evidence to prove the charge against him.
>
> ''I don't want you to feel that it is because obeah has been worked on me that you are being freed. It is only because of a lack of evidence' he said in dismissing the charge.
>
> ''Police detective Charles Moss told the court that he arrested Lazaique on July 28, after he executed a search warrant at the defendant's home.
>
> ''He found the defendant at home at the time with several women waiting in his living room and a woman with a baby with him in a bedroom that smelled of incense, Det. Moss said.
>
> ''Also found was a jacket with $457.22 and a sign reading 'No credit,' and 'Pay Half Down' and the other items including the egg, he said.
>
> ''Det. Moss said that he went to Lazaique's home after a complaint was made by a woman who said she paid him $3 to dress a candle but never received it.
>
> ''The woman had gone to Lazaique because she was having problems keeping her husband at home and away from other women, the court was told.
>
> ''Det. Moss, who said that he was satisfied that Lazaique was practising obeah for gain after speaking with him, had also produced a ledger which he said contained the names of the defendant's clients.
>
> ''The book included the names of several policemen, the Chief Magistrate himself, and also his other two colleagues on the bench, Magistrates George Hannays and Emmanuel Osadebay.
>
> ''Questioned by the magistrate after his evidence in chief, Det. Moss was asked whether he had ever visited a Roman Catholic church and seen their candles on the altar or the incense and holy water used in ritual.
>
> ''He had, he told the court, and also admitted further having common knowledge that people regularly go to the psychiatrists at the Mental Rehabilitation Centre because they have problems.
>
> ''In each case, it was never known why the priests or psychiatrists were never brought to court for practising obeah.
>
> ''He found that on the facts submitted in the case, he was not able to conclude that the defendant was practising obeah for gain. He said that Lazaique's statement to police also told the court that he was a spiritualist—'a person who helps people to solve their problems through prayers.'
>
> ''The mere possession of these items alone is not an offence, Mr. Hercules said, agreeing with an earlier submission made by Mr. Bostwick who said that there was no case made out against Lazaique.''

It is particularly interesting to note the inference in the article that members of the judiciary may avail themselves of the services of Obeah practitioners. Indeed, I have been told on four individual

instances by people in whom I have confidence that more than one member of the Bahamian Parliament regularly avail themselves of Obeah in reaching decisions of import to the nation. One Senator in particular reputedly never casts a vote without first consulting an Obeah practitioner for his opinion as to the effects of a given vote. I have no objective, concrete evidence to substantiate these statements, but I do submit there is little reason to doubt such facts, in that I personally know three Bahamians, all of whom are professional people, two of whom have college degrees, who regularly consult ''spiritualists'' (Obeah practitioners) for guidance in their lives. It is a bit disquieting to consider the possibility that semi-literate charlatans purporting to be quite omniscient may have a profound effect on the governance of a nation.

As for Mr. Rolle, Dr. McCartney dissuaded me from even visiting him, pointing out that in his book on Obeah (McCartney, 1976:70-73) he had quite well documented Rolle's role as a fraud insofar as the practice of Obeah is concerned. Mr. Rolle's *modus operandi* was to offer to cut cards (to read a fortune) or to read a palm, either activity costing $15.00. Reading the client's ''shadow'' (spirit) ran $20.00. He quite readily agreed to read McCartney's palm, however, for $10.00 when the latter indicated that he had only that amount of money. Mr. Rolle—who is of Haitian-Bahamian background—evidently combined a garble of patois and English in an incantation which McCartney recorded as ''Hm. . .power. . .s'il tu plait, s'il tu plait, hm. . .eiee. . .s'il tu plait, s'il tu plait. . .'' (McCartney, 1976:71). McCartney goes on to indicate that this gibberish continued for some time while Rolle pressed McCartney's hand in his. This entire procedure took place in the presence of two ''magical'' books placed on the floor, one in front of each of the client's feet. Written in French, the title of the books was ''How to Become a Millionaire''. . .Other than repeating preliminary information gleaned from McCartney in conversation, the man fabricated all sorts of things which he thought his client would want to hear. McCartney's assessment was that ''I emerged into the bright Bahamian sunlight, with mixed emotions about how I was easily defrauded of my hard-earned $10 . . .''.

This left Cubell ''Killer'' McCoy, a former heavyweight boxer and present-day truck gardener living in the Fox Hill area, near where Pa Beah resided. ''Killer's'' main claim to fame, aside from his purported ability at Obeah, is that he served as a sparring partner for Billy Conn and for Joe Louis in the late 1930s. He delights in showing his ham-like fist to the stranger who visits his sidewalk vegetable and fruit stand and one cannot help but be impressed if, for nothing else, the sheer physical presence of the now elderly gentleman. A gentle fellow, somewhat given to bragadoccio, he claimed in both 1977 and 1979 to have been a pupil of Pa Beah. Despite his offer, in 1977, to demonstrate some of his powers, only two vestiges were forthcoming. First was a view of the bottles and crosses (red on a black background, in traditional Obeah fashion) which he had placed to guard his garden from ''t' iefing''. He assured me that the presence of those symbols of power were quite effective. He also inferred that his tomatoes, which he proudly displayed, owed their fine quality to his mysterious abilities. I must admit that the tomatoes were well-formed and of excellent taste, but I suspect that the average-size fruit which they were acquired their quality from the rather liberal use of horse manure and obviously well-tended hills rather than to any occult reason. ''Killer's'' *piece de resistance* was to be a demonstration of how he could control animals through his will power. He indicated that he would use his own dog (perhaps not the most objective manner in which to demonstrate such power) and show how the dog would go, come, sit, talk (!), and run away simply by ''Killer's'' talking to him. What transpired was that his friendly, large old cur did, indeed, sit down and watch ''Killer'' intently as he gesticulated and ordered his dog to do various things, the dog cocking his head from side to side occasionally, scratched rather energetically and, finally, gave vent to a huge yawn before arising, sniffing at my feet, licking my hand and trotting off to perform a time-honored function at the nearest light pole. ''Killer'' muttered something to the effect that ''de damned dog stupid'' and that ''de vibrations not right''. ''Killer'' was obviously embarrassed, and no amount of cajoling, persuasion, and even a diplomatic offer of payment on my part could convince him to attempt some other demonstration of his Obeah powers. When I last saw him, he was muttering to himself and packing up his wares preparatory to leaving his stand, even though it was just mid-morning. It is important to remember that I did not approach him unaware, it was he who had offered to perform the demonstration for me.

This had exhausted all of the ready possibilities open to me for visiting with and witnessing the performance of an Obeah practitioner. There were left only three possibilities to make good on my intent to find at least one legitimate vestige of Obeah as a supernatural function.

First, Dr. McCartney had often spoken to me about a lady whom he described (McCartney, 1976:80) as an Obeah practitioner with whom he had ''become very friendly. . . and [I] use her as my 'consultant' in occult psychology, when I deal with Obeah problems. I have found her to be honest, non-mercenary, and utilising, primarily, bush medicine and white magic.'' This lady, who must remain anonymous was, in 1979, 68 years of age and was born on Long Island, Bahamas. Her father was a native of Cat Island, and was reputed to be an excellent bush medicine man. It was from him that she learned at an early age to distinguish the various bushes and barks and their effects on the human body and mind. Her mother was originally from Long Island, but left her husband and daughter while living on Cat Island. This lady grew up under the influence and tutelage of her father and reportedly had ''visions'' from an early age. Her father originally passed them off as bad dreams, but eventually came to feel that his daughter was clairvoyant and referred to her as a ''witch''. McCartney recounts a series of events which occurred during a meeting with her (McCartney, 1976:81-85) which, if taken at face value, are indeed extraordinary. Those events are not directly germane here, for I never had the opportunity to meet this lady. Tim tried to set up a meeting for me, only to learn that the lady was in the hospital in very grave condition. Subsequently, it was learned that she had been transported to Miami to a hospiital there for further medical attention. Therefore, I have only at second hand the fact that she is capable of performing, or causing it to appear that, phenomenal events are taking place. While I respect Dr. McCartney's word and certainly have no reason to disbelieve him, I cannot say factually that this lady is any more capable at Obeah practices than any of the other figures purporting to possess the power.

What is particularly disgusting on today's Obeah scene is to see the commercial products which are being peddled by the frauds to their clientele. At exorbitant prices ($5 for a tiny bottle, for example), one can purchase such nostrums as ''Fast Success'' powder; ''Lucky Dream Remembering Oil''; ''Lucky Dream incense'' and ''Holy Spirit Bath''. These items are all manufactured in Miami, Florida and are labeled as ''curios'', sold by Sonny Boy's Products or the St. John's Religious Store. The titles are more or less self-explanatory, the contents purporting to bring one good luck (e.g., at the race track or in one's love life) or to bring more money to the consumer, etc. Under no circumstance should these whimsical commercial products be confused with bush medicine, or even with ''legitimate'' items prepared by an Obeah practitioner.

One other incident of the 1979 field session deserves comment. On my arrival in Nassau, I was greeted by four acquaintances with the query ''Why weren't you here in May when the things happened at the house on Collins Avenue?'' Obviously, something important had happened, but I was in ignorance of just what. Through questions and the reading of back issues of *The Nassau Guardian,* the following story emerged. An elderly couple called the police to inform them of some very strange and frightening happenings at their modest home. As pieced together, a pair of shoes—sans person wearing them—was walking down the sidewalk outside the house; on the interior of the home, rocks were flying through the air and had broken out the glasses of a commode (a small china cupboard) as well as breaking a dresser mirror in the bedroom; a very strong stench of old urine prevailed in the bedroom and a disembodied penis had spoken to the old gentleman. A large crowd of curiosity seekers got word of the weird happenings and, in effect, stormed the house, breaking down the fence, smashing the exterior front door, and trampling what grass there had been. Police estimated that over 2,000 people were surrounding the dwelling at one point and riot-control procedures had to be put in effect. Newspaper accounts averred that several clergymen and an African ''witch-doctor'' who was lecturing in Nassau at the time had visited the home, but had no explanation for the happenings.

These events could not help but pique my curiosity, so I spoke with some contacts within the Criminal Investigation Department of the police, and talked with other informants about the situation preparatory to visiting the house. I discovered that the gentleman of the house, an elderly Cat Islander, was prone to overuse alcohol; that he had previously ''seen things'' when under the influence, and that it was suspected that a charge for admission to the house was to be levied when the miraculous happenings were known. It was theorized that the scheme was, in one sense,

too successful and that the onslaught of the crowd previously mentioned completely unnerved the man and his wife. It is significant that only one other person, a young policeman—and a relative of the principal character in this story—claims to have seen anything untoward about the house that night. And whatever the strange thing was that the young man professed to have seen was never specified.

Nonetheless, as the ''visiting expert'', I was goaded to visit the house and, I must admit, it did not take too much persuading for I, too, was curious. I arrived at the house at about 11:00 a.m. to find the occupants, the elderly couple and their 30-year old mentally retarded son, taking the air on the front porch of the house. Evidences of the damage by the crowd were still to be seen—the trampled lawn, broken-off flowers, smashed door. I was cordially offered a stool and sat to talk with them. It very soon became obvious that the old fellow had already been sampling some form of alcohol rather liberally, but he was basically coherent in speech. His wife, perhaps also affected by the bottled spirits, soon launched into a tirade against her husband and ''all those others'' for ruining her flower garden and for ''breakin' up de doh''. After he had rather abruptly silenced her with a verbal admonition as to what might befall her if she did not ''shut her mouth'', he then launched into a litany about the poverty in which they lived and how much they needed money. After about one-half hour of this type of conversation, I finally was able to steer the talk back to the mysterious happenings and they agreed to let me see the interior of the house and to show me the precise places where things were broken, etc.

First I was shown the dish commode which had had its glass smashed out by the flying rocks. Interestingly, not one of the nine panels where glass should have been in the small (approximately 1.5 meters tall x 75 centimeters wide) cabinet had any glass at all. The piece was obviously hand-crafted, and unfinished. Not one sherd of glass was to be seen around or in the piece of furniture and examination of the mortice work with a 10x Hastings Triplet loupe failed to reveal any sign of glass ever having been installed in the cupboard. The lady of the house indicated that she had swept out the broken glass, although the appearance of the floors throughout the home tended to cast doubt on the frequency of any sweeping.

Next, I inspected the dresser where the mirror was reportedly broken out by rocks. This piece of furniture was an inexpensive, commercially manufactured item and, indeed, had a stand on which a mirror should have been. Again, there was no sign of any sherd of glass or glass splinters to be found. Further, the stand on which the mirror should have been mounted had no mortice work to receive a mirror, but was backed with a cardboard to which inexpensive mirrors are routinely glued on this type of furniture. There was no indication of any type of glue ever having been on the carboard which leads one to question if any mirror had ever been present. As was the case with the dish commode, there was absolutely no denting, scraping, abrasion or other mark which one might expect to find from rocks hitting an object with some force, nor were there any scratch marks from the putative broken glass.

The rocks had mysteriously flown through the air smashing glass, but had not hit any of the occupants. This was attested to by both the man and woman; the son is incapable of intelligible speech. Both people also agreed, in answer to my question, that rocks had showered down on the roof of the house. I then asked if I might see some of the rocks. Alas, they had all been thrown out. Where? In the garden. Could he point out any one of them to me? No, they all look alike lying with the other gravel in the garden. Might I then borrow the ladder I had seen leaning against the back of the house to view the roof and, perhaps, pick up one of the stones that had rained down? Again, unfortunately, the ladder probably would not hold my weight and, besides, all of the rocks had also been removed from the roof. . .At this juncture, my notes trail off and I must admit that I did not record exactly what it was the the disembodied penis said to the old fellow. As to the stench of urine in the bedroom, I found no reason to doubt that fact. It was a most non-productive, if somewhat bizarre and sad experience. The old man, even given the opportunity to lay some of the happenings to an Obeah ''fix'' opined that Obeah was no factor in the situation.

One thing that has become most apparent is that traditional Obeah practices are, minimally, on the wane if not at the point of extinction. Some of the superficial trappings are extant, e.g., bottles hanging in trees to prevent theft of fruit; ''grave'' dirt for ''fixes''; potions for curing ills; wax ''fixes'', etc. However, the overall picture seems to be that self-proclaimed Obeah practitioners are

nothing more than palmists, fortune-tellers, seers, and other charlatans who are more than ready to relieve their clients of hard-won cash. Owing to the excruciatingly low level of income in Haiti, as one example, there has been an influx of Haitians into the Bahamas, bringing with them a built-in reputation for black magic or ''voodoo''. In fact, an unsophisticated and informal count of so-called Obeahmen in Nassau leads me to believe that the majority of the practitioners are Haitian in origin, with liberal sprinklings of other Caribbean or circum-Caribbean nationalities also having set up shop.

Consultations with an Obeahperson of any type are typically expensive, with prices for the simplest of consultations ranging from $20 to $50 today. I have been informed, although I have no first-hand corroboration of the fact, that charges of up to $500 for services rendered are not uncommon. I have good reason to believe that one distressed lady, working in a governmental position in the Bahamas, paid a total of $1500 for a series of meetings with a practitioner to help her alleviate some severe emotional problems she incurred as a result of a broken marriage. I gather that the practitioner, the name of whom my informant would not divulge, is either Haitian or claims to get his ''powers'' from Haitian connections. I further gather that he must be quite insightful into human problems and frailties and perhaps did serve in a helpful counseling role with this particular lady. She claims complete ''cure'' from her mental distress. Perhaps the end result justifies the means in some cases, but good psychological counseling which is readily available in Nassau would have cost her substantially less with the same probable end results and a certain security of knowing the psychologist would be there at any time he was needed. Obviously, given the technical illegality of Obeah and the naturally transient nature of many of today's practitioners, one cannot count on finding his/her practitioner available from one day to the next.

It is my distinct impression and opinion that Obeah as earlier described in this paper has virtually ceased to exist. The youth of the Bahamas are becoming less and less sanguine about any real belief in Obeah; the overall population is becoming more cosmopolitan in outlook; hundreds of thousands of foreign tourists flowing in and out of the major ports have substantially altered the social outlook of the Bahamians; the ''Out Islands'' are steadily being drawn into a cohesive national identity and the mainstream of world view; educational standards are rising; medical practice is improving by leaps and bounds. In short, Obeah as such either has become, or soon will reach the status of being an anachronism in the Bahamas.

Some Obeah-Connected Superstitions

The residual belief in Obeah among Bahamians is complementary to their beliefs in numerous minor superstitions. Such superstitions are similar in nature to those occuring in many parts of the world, but definitely connected to Obeah in the minds of many. Bahamian examples include such beliefs as:

> To Avoid punishment, pull out an 'eye winker' (eye lash), throw it over your shoulder after spinning around three times.
> If your big toe is shorter than your second toe your Father will die before your Mother.
> If you point a finger at the dead or at a graveyard, your finger will rot off very shortly.
> When your ears are ringing, it means that your lover is talking about you.
> When couples are married, if their wedding day is very rainy, then the couple will never be happy.
> Whenever there is a screeching cricket in the corner of a house, this is a sign of death.
>
> (McCartney, 1976:158,162,164).

In addition, many other superstitions revolve around ''sperrids'' (spirits), graves, ''catching shadows'' (saving in a bottle the last breath, or spirit, of a dying person) and other subjects related to death and dying.

Substantial portions of Bahamian society adhere to these superstitions concerning everyday occurrences, and this lends strongly to the belief in more involved superstitions incorporated within Obeah. This pattern also helps to explain the highly diverse nature of Obeah. The broad framework

of superstitious beliefs allows for a wide range of occurrences to be ''explained'' by superhuman causes. Thus, people are willing to accept a great variety of different situations as being Obeah-derived or -alleviated, although this appears to be limited more and more to the older elements of the population, especially those over the age of about 50.

Conclusion

In the Bahamas, traditional Obeah has historically provided a useful social function by bringing some measure of control (or attempts at control) to situations that are normally uncontrollable. It has provided a means by which ordinary members of society can affect events in their lives, through the application of its practices that are, or were, believed to have the power to influence such events. Its validity as a viable course of action rests on the credibility of the Obeah practitioners and their ability to bring about desired results. Their credibility is maintained, in some respects, by their use of bush medicine, which does have actual healing capabilities, and by their ability to perceive and assess their clients' problems and the latters' faith in the results of Obeah. Foremost, traditional Obeah depends on the fact that a certain group of people strongly believe, and want to continue believing, in its power and abilities. There are some contemporary Obeah practitioners who take advantage of their clients' faith, purposely deceiving them with useless (or even harmful) remedies. However, for those segments of the society who manifest a strong faith in Obeah, it appears to be a valid and socially useful practice—that is, in its helpful forms. It is certainly an intriguing practice, even to those not quite so faithful.

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Plate 1. A self-proclaimed Obeahman, Cubell "Killer" McCoy, at his produce stand.

Plate 2. A mango tree that has been "Fixed", to deter the theft of fruit.

Plate 3. Former home of Pa 'Beah, deceased ''king'' of Obeahmen on New Providence.

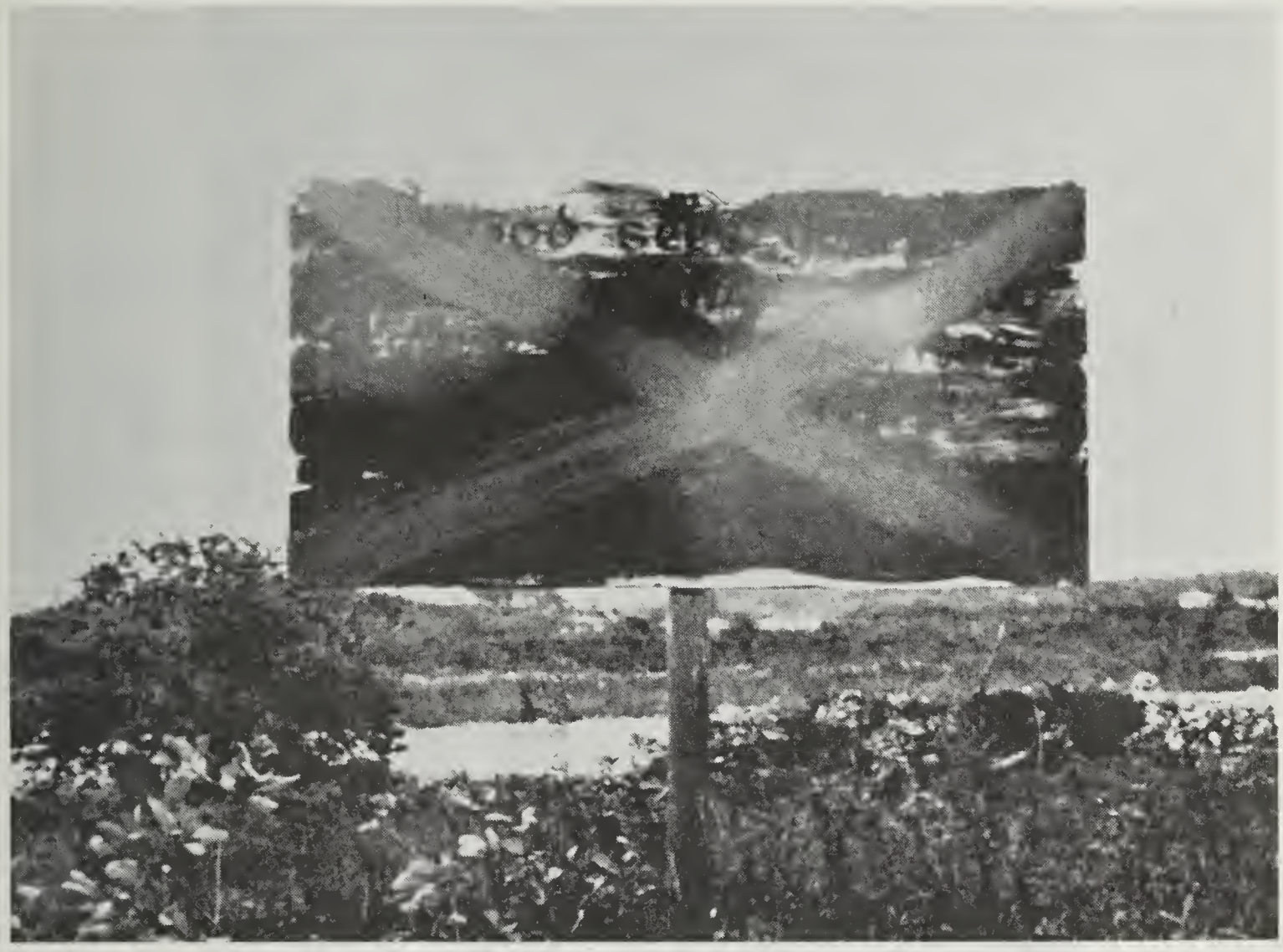

Plate 4. An Obeah ''Flag'' to discourage trespassing on private land. A red cross on black background. Lettering says, in part, ''God sees you''.

Plate 5. Amidst scenery and atmospheres like this, Obeah once fluorished throughout the Bahamas.

Plate 6. A selection of the nostrums peddled by present-day, purported ''obeahmen''.

Plate 7. The constituents of a concoction of ''Sexy Batch'' (see text for details), a bush-medicine currently being sold on various islands of the Bahamas.

Plate 8. A bottle full of ''Sexy Batch''. The constituents shown in Plate 7 are steeped in water to produce the brew.

NOTES

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